AD-780 013

AIRDROP CONTROLLED EXIT (ACE) SYSTEMS

G. L. Fritzler

MB Associates

Prepared for:

Army Natick Laboratories

July 1973

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-780013

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-74-38-AD	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Airdrop Controlled Exit (ACE) Systems		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G. L. FRITZLER		8. CONTRACT OR GRANT NUMBER(s) DAAG 17-72-C-0192
9. PERFORMING ORGANIZATION NAME AND ADDRESS MB Associates San Ramon California		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1F162203AA33
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Laboratories STSNL-AAP Natick, Mass. 01760		12. REPORT DATE Jul 73
		13. NUMBER OF PAGES 143
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution of this document is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

See reverse

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was conducted to identify and compare techniques which minimize ground dispersion of either airdropped troops or platform loads caused by the time increment between sequential exit from the aircraft. Twenty (20) concepts for platform loads and seven (7) concepts for personnel airdrop were determined to have sufficient merit for consideration as operational airdrop systems. Each of these systems

(Continued on reverse)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

19. Key Words	Link A Role	Link B Role	Link C Role
Tests	8		
Optimization	8		
Minimization	8		4
Ground Dispersion	9		4
Extraction	9		
Platforms	9	9	
Loads (Platform)	9	9	
Airdrop Operations	4		
Military Personnel	4		
Stresses		8	
Deflection		8	
Deployment		10	
Parachutes		10	
Aerial Delivery		4	
Evaluation			8
Airdrop Systems			9

---

20. Abstract Continued:

reduce drop zone dispersion from that achieved with the presently operational systems. Some of the concepts, however, are diminished in value from a systems standpoint in that attainment of shorter drop zones is accomplished only by introducing some operationally undesirable system characteristic. A comparative evaluation is performed by a scheme that produces figures of merit whereby concepts for either type of airdrop may be compared among themselves and with the currently operational systems.

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

FOREWORD

This work was performed under U. S. Army Natick Laboratories Contract No. DAAG 17-72-C-0192 during the period of 30 June 72 - 1 Jul 73. The Project No. was 1FJ62203AA33 entitled "Exploratory Development of Airdrop Systems", the Task No. was 04 entitled "Airdrop Controlled Exit Systems (ACES)". Mr. Arthur L. Murphy Jr. of the Airdrop Engineering Laboratory served as the project officer.

The effectiveness of an airborne assault is greatly reduced because of the scatter of men and equipment in the drop area. These dispersions result directly from the manner in which the multiple delivery of paratroops or platform mounted cargo is effected. In so far as airdrop systems influence dispersion patterns, solutions to this problem are investigated in this study emphasizing current airdrop methods and state-of-the-art technology. The primary concern of this effort is to identify candidate systems which will materially minimize either the extraction cycle of sequentially extracted platforms or substantially reduce the aircraft exit time for paratroops.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

1.0 INTRODUCTION

Reduction of dispersion of airdropped personnel and equipment on a drop zone enhances the effectiveness of an airborne operation. The present study was conducted to address that segment of total drop zone dispersion attributable to the time increment between either the sequential exit of troops or platform loads from the drop aircraft.

A single C-141 aircraft requires over 13,000 linear feet of terrain to discharge its full complement of 123 men and their personal equipment. The same aircraft dropping sequential platform loads requires approximately 1000 feet of drop zone length for each platform dropped or about 7000 feet for a typical full aircraft load. Typical aircraft speed during an airdrop is 130 knots. Increase in airspeed will contribute further to the length of drop zone required. Additional factors such as aircraft positioning, variable winds, individual parachute ballistics, and spacing and sequencing of aircraft in formation conducting multiple drops will increase the drop area.

The current framework of airdrop methods, that is, aircraft of the C-130, C-141 and C-5A type utilizing parachute delivery allows, in general, two approaches from which to formulate solutions to the problem of dispersion: (1) Exercise control of the exit phase from the aircraft and/or (2) Provide control to the trajectory after the item has left the aircraft.

Airdrop by conventional parachute from altitudes in excess of 2000 feet above the drop zone can introduce large inaccuracies and dispersions arising primarily from wind variations and aircraft positioning errors. For airdrop at these higher altitudes, the approach to the dispersion problem is largely one of trajectory control.

For airdrop below 2000 feet above the ground, the problem of longitudinal dispersions or displacements attributable to the time required to discharge each individual item from an aircraft traveling at high speed is paramount. It is essentially an exit problem constrained by the aircraft and aircraft-parachute deployment phase interface. This is the area to which this study is specifically addressed. It has been the objective of the contract to provide the ground work leading to the development of Airdrop Controlled Exit (ACE) Systems for (1) Airdrop of Personnel and (2) Airdrop of Platform Loads extracted in sequence.

2.0 APPROACH TO THE PROBLEM

The ACE program was conducted in four individual phases in accordance with the Program Plan and Program Schedule presented in Appendix A.

Phase I of the program was a Historical and Operational Review of the development and current state of airdrop technology. This phase consisted of a comprehensive literature review and technical discussions with individuals from several organizations concerned with airdrop. A number of pertinent information sources are listed in the section entitled "Selected Bibliography". The organizations contacted for the purpose of gaining insight into airdrop operational and developmental activities included the following:

- Airdrop Engineering Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts
- Equipment Development Branch, Delivery and Retrieval Division, Aircraft Systems Division, Wright-Patterson Air Force Base, Ohio
- U. S. Army Airborne, Communications and Electronics Board, Fort Bragg, North Carolina
- Combat Tactics Group, 86th Military Airlift Squadron, Travis Air Force Base, California
- 6511 Test Group, Naval Air Test Facility, El Centro, California

Phase II was entitled Concept Formulation. During this phase the following tasks were accomplished:

- Analytical determinations were made of minimum paratrooper jump interval allowable for single egress points.
- Computerized trajectory studies were made to determine the effectiveness of trajectory modification techniques for drop zone length reduction for cargo drops.
- Generalized calculations of force and power requirements were made for cargo extraction and personnel conveying systems.
- Determination was made of Airdrop System constraints imposed by aircraft design and

performance, operational considerations imposed by the needs of U. S. Army field commanders, and cost of delivery of airdrop items.

- All known existing ACE concepts for personnel and platform loads were described and preliminarily characterized in terms of operation, performance, and installation.

Phase III, System Synthesis, was accomplished to synthesize new ACE concepts for both personnel and platform load airdrop.

Phase IV, Systems Evaluation, was accomplished to determine a figure of merit scheme with which to compare and evaluate the ACE concepts which were determined to be worthy of further study. Twenty concepts for platform loads and seven concepts for personnel drop were evaluated. Recommendations were made relative to which systems should be given further study based upon the Systems Evaluation accomplished.

3.0 SYSTEMS ANALYSIS

Certain preliminary calculations were accomplished early in the program to give analytical guidance in thinking about feasibility of ACE concepts. Several of the more pertinent calculations are summarized in this section. Of particular importance are (1) calculations of paratrooper separation distances during sequential exit and (2) an analytical treatment of the parachute extraction process. The separation distance calculations point up the need for ACE systems to cause spatial separation of jump personnel outside the aircraft. The extraction parachute process analysis illustrates several areas of potential improvement in these types of systems.

3.1 Calculated Separation Distances Between Parachutists for Various Jump Intervals

Machine computed parachutists trajectories are used to determine the magnitude of acceptably short jump intervals which allow maximum egress rate without causing interference between parachutists outside of the aircraft.

The trajectory program used (Reference 1) is one developed by Dr. Gregory DeSantis of the Airdrop Engineering Laboratory, U. S. Army Natick Laboratories. Among other things, this computer simulation has been shown to very accurately predict positions of both a point on the parachute and a point on the parachutists's body as functions of time for the static line deployed T-10 parachute system. Figure 3-1 shows these trajectories for the following input conditions which are felt to be typical:

Aircraft Data

Aircraft Indicated Airspeed	125 knots
Aircraft Altitude	1000 ft. MSL
Aircraft True Airspeed	126.85 knots

Parachutist Data

Weight of Parachutist in Jump Clothing	215 lbs.
Drag Area of Parachutist ($C_D A$)	4.14 ft^2

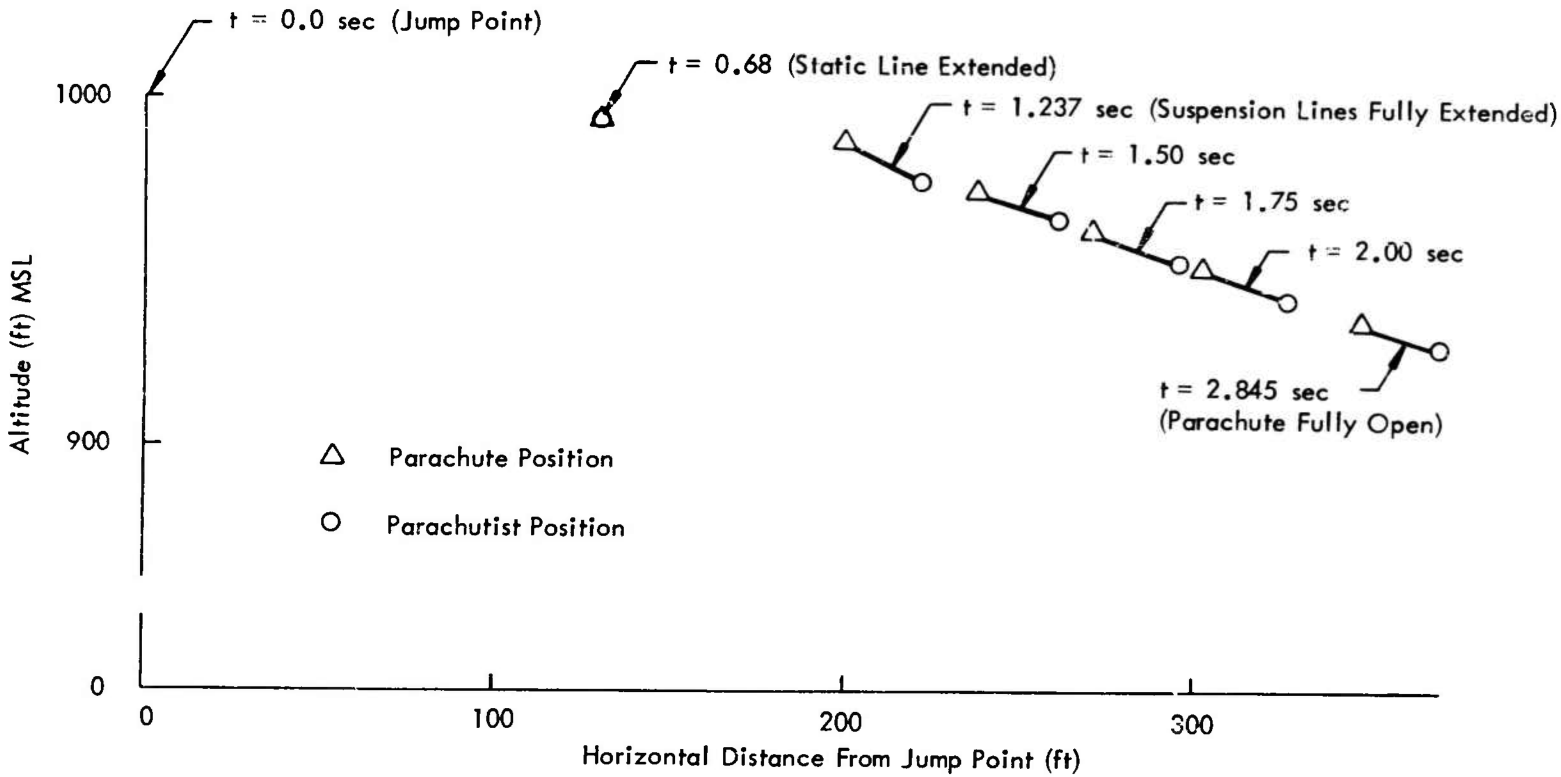


FIGURE 3-1
COMPUTED PARACHUTIST TRAJECTORY

Parachutist Drag Loading	51.91 lb/ft^2
Static Line Length	15 ft.

<u>T-10 Parachute Data</u>

Extended Skirt Parachute with 10% Extension	
Nominal Diameter	30 ft.
Total Length of Suspension Line and Riser	25.5 ft.
Ratio of Suspension Line Length to Parachute Diameter	0.85
Number of Gores in Parachute	30
Ultimate Breaking Strength of Suspension Lines	375 lbs.
Percent Elongation of Suspension Lines at Rupture	32%
Parachute Vent Diameter	1.5 ft.
Weight of Parachute Material	1.10 oz/yd^2
Weight of Parachute	14.1 lbs.
Drag Area of Deployment Bag (C_DA)	1.9 ft^2
Parachute Pack Drag Loading	7.34 $\frac{lb}{ft^2}$

<u>Drop Zone Data</u>

Elevation	0 ft MSL
Wind	0

Two identical parachutists jumping sequentially follow similar but horizontally separated trajectories with respect to a fixed (earth) frame of reference, but follow identical trajectories with respect to a frame of reference moving with the aircraft. The parachute and parachutists positions may be made relative to the aircraft position by subtracting the product of aircraft true air speed and time at a spatial position from the horizontal distance traveled by the parachutist at the particular time of interest.

The computed parachute and parachutist trajectories relative to the drop aircraft are shown in Figure 3-2. The paths followed relative to the aircraft are identical for all jumpers; however, the times which a particular relative position is occuped by two sequential jumpers are separated by exactly the jump interval between jumpers. In Figure 3-2, at each of the several relative trajectory positions indicated, t_1 indicates the time at which the first jumper occupies that position relative to the aircraft, and t_2 indicates the time at which the second jumper is in that position relative to the aircraft. At any relative trajectory position, t_2 is simply t_1 plus the jump interval.

Separation distance between deploying parachutes of two sequential men in a stick as a function of time is then determined by scaling from plots like Figure 3-2 the distance between relative positions which exist with t_1 equal to t_2. Plots similar to Figure 3-2 were prepared for jump intervals of 1.0, 0.5 and 0.3 seconds. Separation distance between men and/or parachutes was graphically determined and the results are presented in Figure 3-3 wherein minimum distance is shown as a function of time for the several jump intervals considered.

It is readily seen that the closest proximity between two jumpers occurs at the time the second of the two exits the aircraft. The separation rapidly increases thereafter as drag of the first jumper quickly increased with the deployment of his parachute. Separation which occurs at the time the second jumper leaves the aircraft, therefore, is the only consideration in determining minimum jump interval. Figure 3-4 shows the minimum separation between points on two sequentially jumping parachutists at the time the second exits the aircraft as a function of length of jump interval.

It appears from Figures 3-3 and 3-4 that jump intervals of less than about 0.4 seconds would provide marginally short minimum separation distances (less than about 4.5 ft.). Separation distance increases rapidly with time after the parachutist exits the aircraft, but the analysis presented does not account for variations in drag area, weight or tumbling characteristics of individual jumpers. Additionally, the separation distances indicated for short jump intervals are measured from a point on a jumper to the same point on another jumper, and do not consider the physical length of extremities of jumpers which may contact an adjacent jumper.

It becomes obvious from the present analysis that ACE concepts for personnel airdrop must provide for physical separation of parachutists outside of the aircraft when egress rates per exit become attractively high.

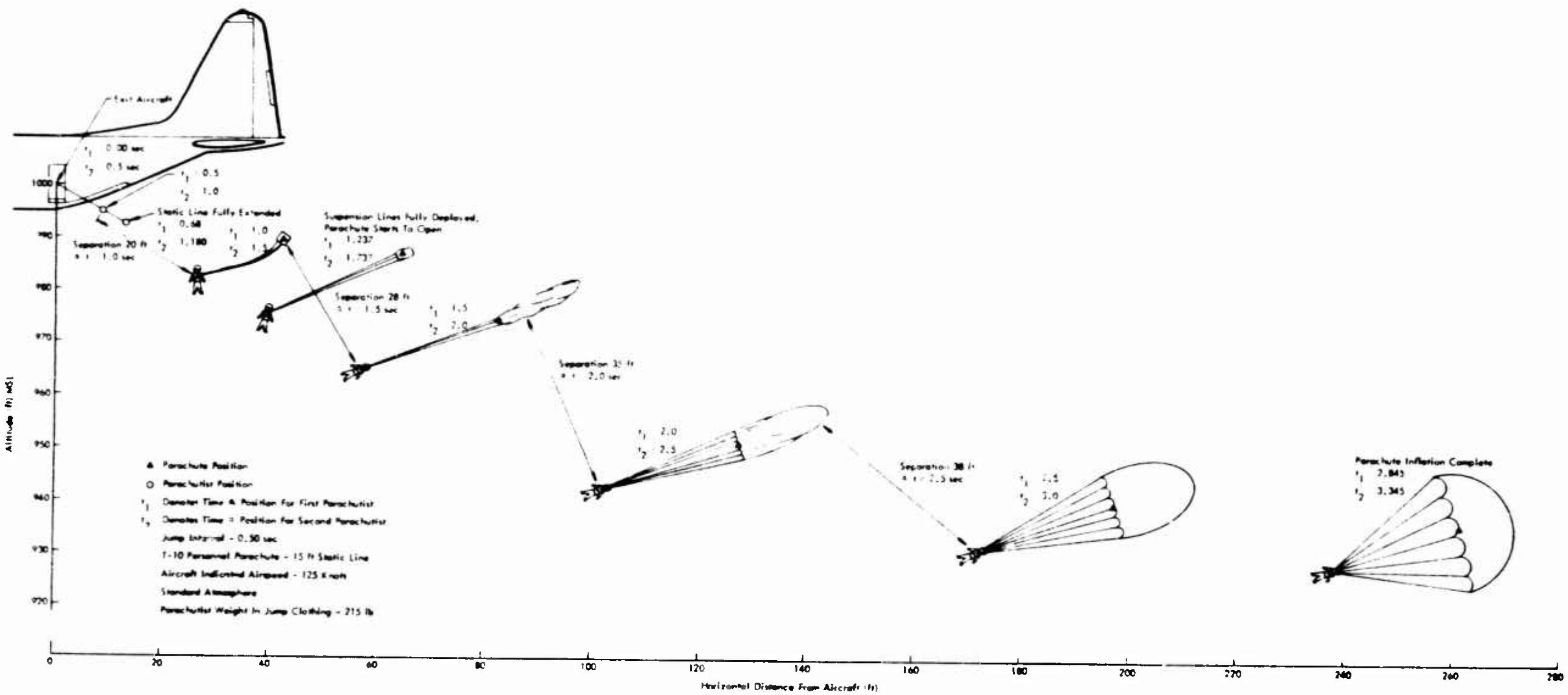


FIGURE 3-2.
CALCULATED PARACHUTIST TRAJECTORY RELATIVE TO AIRCRAFT

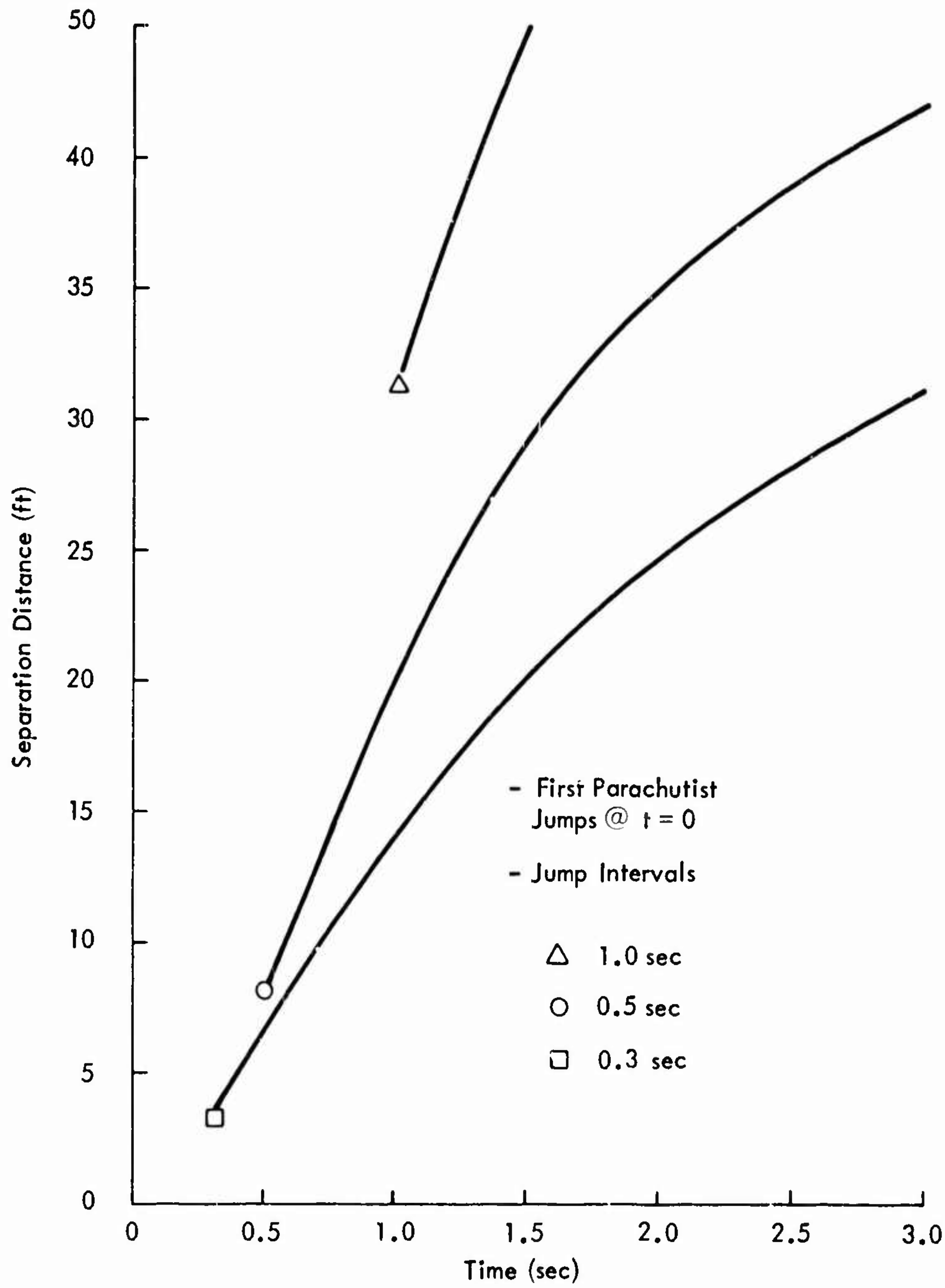


FIGURE 3-3.
PARACHUTIST SEPARATION DISTANCE AS A FUNCTION OF TIME FOR SEVERAL JUMP INTERVALS

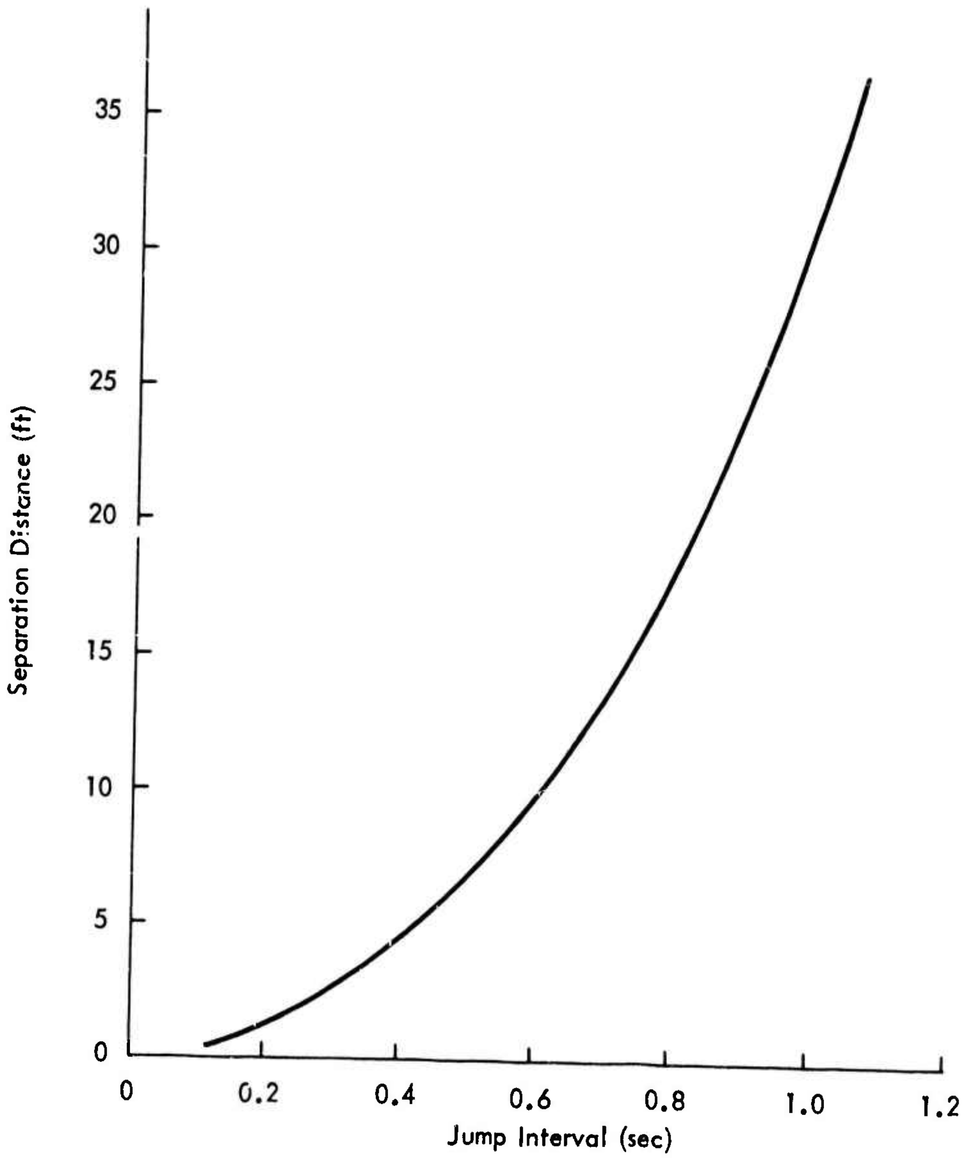


FIGURE 3-4.
MINIMUM SEPARATION DISTANCE AS A FUNCTION OF JUMP INTERVAL

It is noted that the simplified analysis described in Appendix C predicts horizontal separation of sequential parachutists very close to those predicted using the technique herein described. If vertical displacement from the aircraft is taken as $1/2\ gt^2$ and the horizontal separation is predicted by the technique of Appendix C up until the time the parachute starts to produce significant drag, the early trajectory of parachutist may be quite accurately and simply predicted without using the sophisticated computer techniques.

3.2 Approximate Performance of Extraction Parachute Systems

Approximate relationships between several parameters affecting performance of extraction parachute systems are developed herein. Some useful calculated results are presented graphically to allow rapid comparisons of extraction system variants.

The drag force on an extraction parachute is

$$D = C_D A \ 1/2 \ \rho V^2 \quad . \tag{1}$$

If friction and aircraft deck angle are neglected, the only significant force acting on a platform load during extraction is the drag of the extraction parachute. The acceleration of the load due to the extraction force is

$$a = \frac{dV}{dt} = - \frac{C_D A \ \frac{1}{2} \ \rho V^2}{m} \quad . \tag{2}$$

If the parachute is very nearly fully inflated at the time the platform is released by the spring loaded detents of the dual rail system, parachute area can be assumed constant and the parameter

$$\lambda = \frac{2m}{\rho \ C_D A} \tag{3}$$

is a constant commonly called the "slowing-down length" in ballistics. The slowing-down length arises naturally from the differential equation of motion of a horizontal trajectory with drag:

$$\frac{dV}{dt} = - \frac{V^2}{\lambda} \quad . \tag{4}$$

Dividing both sides of Equation (4) by $V = \frac{ds}{dt}$ yields

$$\frac{dV}{ds} = - \frac{V}{\lambda} \tag{5}$$

which immediately leads to the solution for velocity as a function of distance of a body with initial velocity, V_o, following a horizontal trajectory under the influence of aerodynamic drag alone:

$$V = V_o e^{-\frac{s}{\lambda}} \tag{6}$$

The slowing down length is then the distance at which the body has decelerated to $V = \frac{V_o}{e}$.

Equation (4) can also be integrated to produce velocity as a function of time. If initial conditions are determined to be $V = V_o$ at $t = o$, integration of (4) produces

$$V = \frac{ds}{dt} = \frac{1}{\frac{1}{\lambda} t + \frac{1}{V_o}} \tag{7}$$

The difference in velocity of the platform and aircraft at time t is

$$\Delta V = V_o - V \tag{8}$$

Equation (7) can also be integrated to determine displacement as a function of time. If initial conditions are taken as $s = o$ at $t = o$, integration of (7) results in:

$$s = \lambda \ln \frac{V_o}{\lambda} t + 1 \tag{9}$$

The distance a platform load has moved aft of its initial position in the aircraft at time t during the extraction process is

$$\Delta X = V_o t - s \quad . \tag{10}$$

Drag coefficients for extraction parachutes may be determined using the drag values for towed ring-slot extraction parachutes presented in Reference 2. It can be shown that a drag coefficient of $C_D = 0.52$ based upon a reference area equal to the area of the parachute in a flat (uninflated) condition is a fairly good value for all parachutes being considered. The inflated diameter of a ring-slot parachute is about 0.7 times the flat (nominal) diameter. A drag coefficient based upon a reference area equal to the projected area of the inflated parachute is therefore $C_D \approx 1$.

The very useful parameter slowing down length (λ) may be calculated using Equation (3) for any combination of platform load mass, extraction parachute size and atmospheric density. Figure 3-5 shows slowing-down length as a function of platform load mass for the several parachutes being considered with density taken as that on a standard day at sea level.

Reference 3 specifies the range of platform load mass allowable for each type of extraction parachute used in conjunction with the C-130 aircraft with airdrop speeds limited to a maximum of 130 knots indicated air speed.

The specified range of platform mass for each extraction parachute is that which is between the limits established by dot marks on each curve in Figure 3-5.

Equation (4) relates the deceleration of an extracted platform load to its velocity and slowing-down length. The maximum deceleration occurs at the instant that the parachute is fully inflated and the platform load still is approximately at the aircraft velocity. The maximum acceleration experienced is often expressed as the ratio of peak extraction force to platform load weight (Extraction Ratio). The Extraction Ratio in normal airdrop operations is maintained between 0.7 and 1.5. Figure 3-6 shows Extraction Ratio as a function of slowing-down length for several pertinent aircraft true air speeds. Figures 3-5 and 3-6 may be used to determine peak acceleration experienced by a platform load for a given aircraft speed and parachute type. Conversely, the figures may be used in conjunction to determine an applicable parachute for a desired extraction ratio.

Equations (9) and (10) allow determination of the distance aft a platform moves (relative to its initial position in the aircraft) as a function of time after detent release. Figures 3-7 through 3-9 show separation distance ΔX as functions of slowing-down length and time for the air speeds of interest.

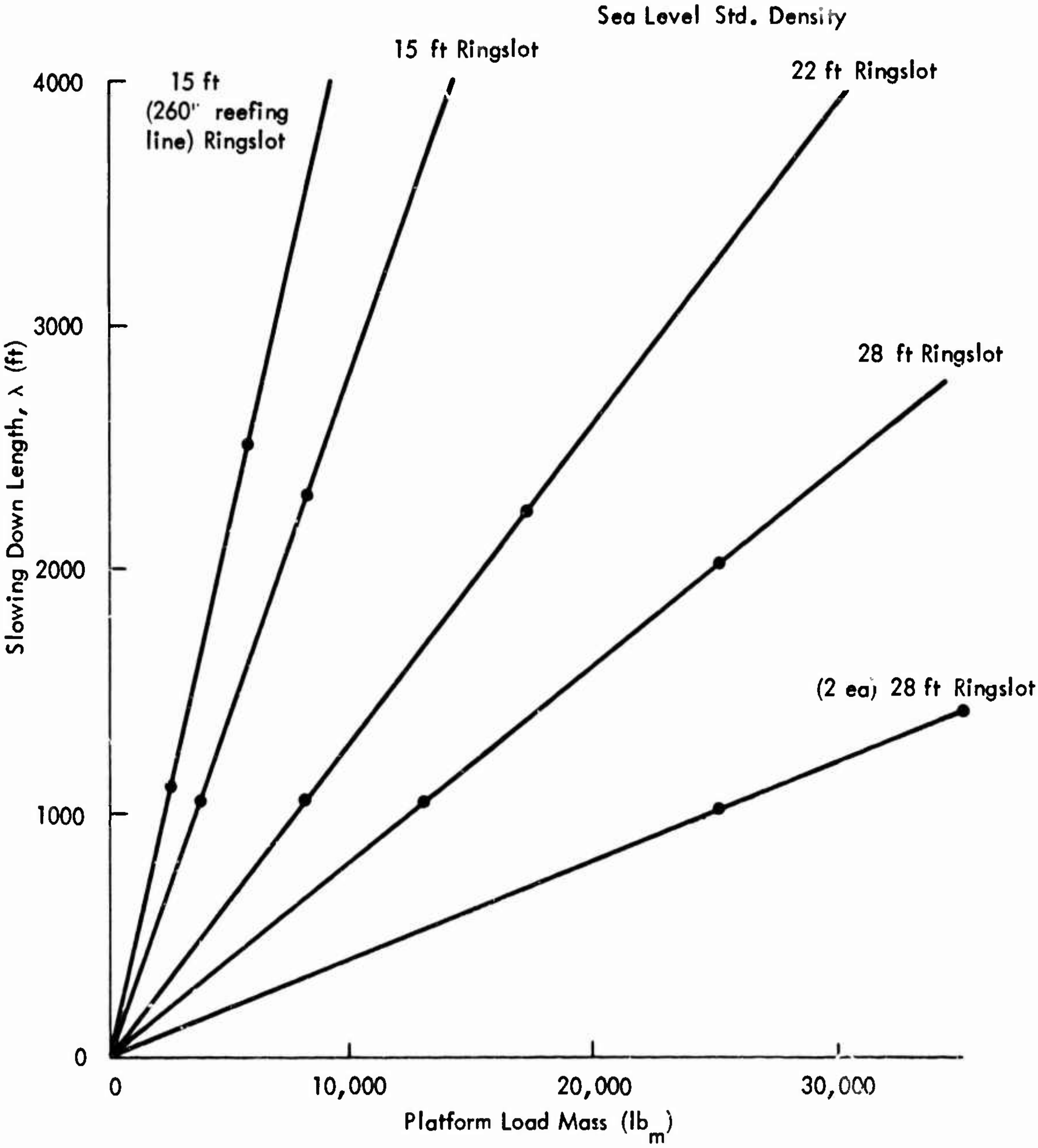


FIGURE 3-5
SLOWING DOWN LENGTH VS PLATFORM
LOAD MASS FOR 5 EXTRACTION PARACHUTES

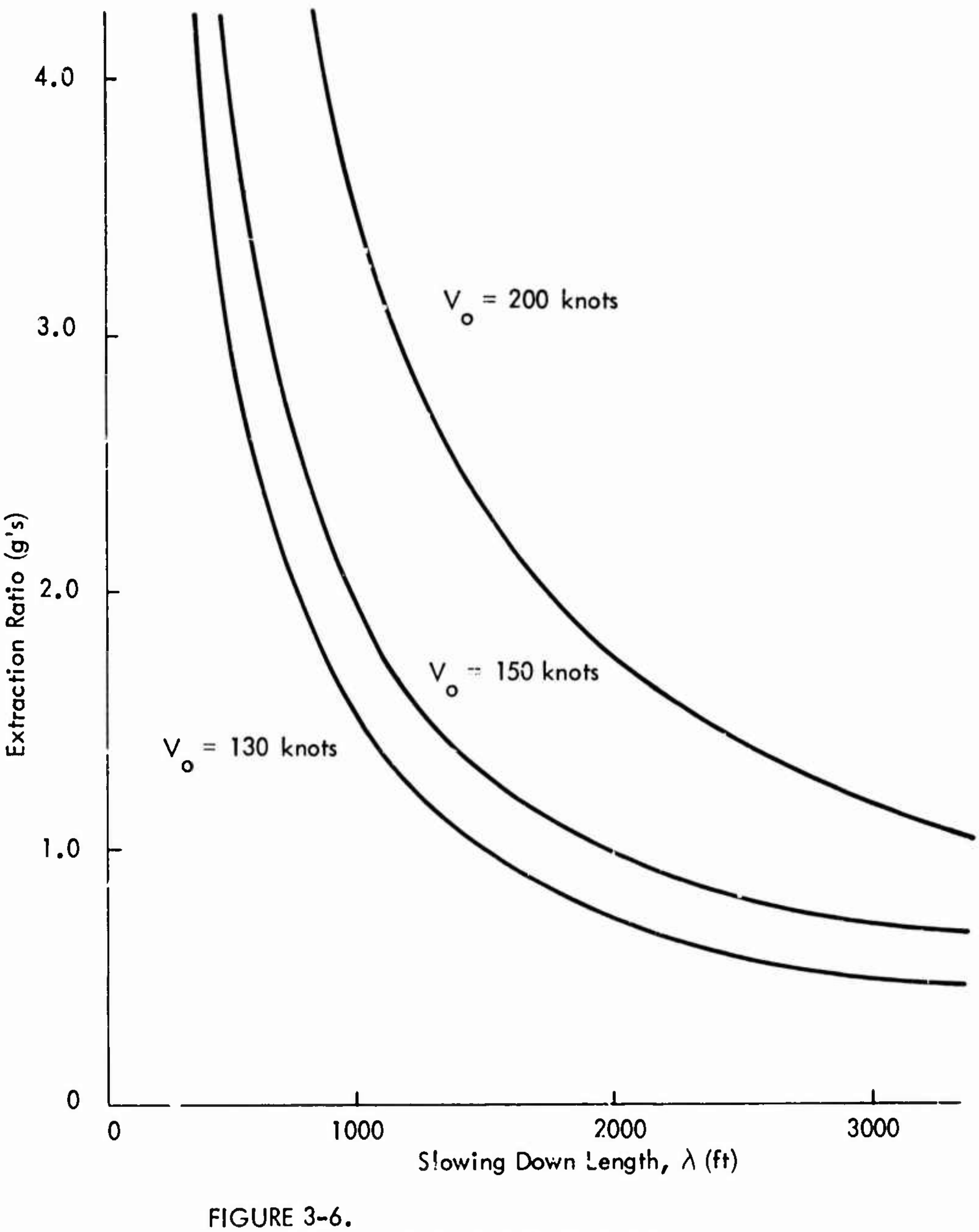


FIGURE 3-6.
EXTRACTION RATIO VS SLOWING DOWN LENGTH FOR 3 AIRCRAFT VELOCITIES

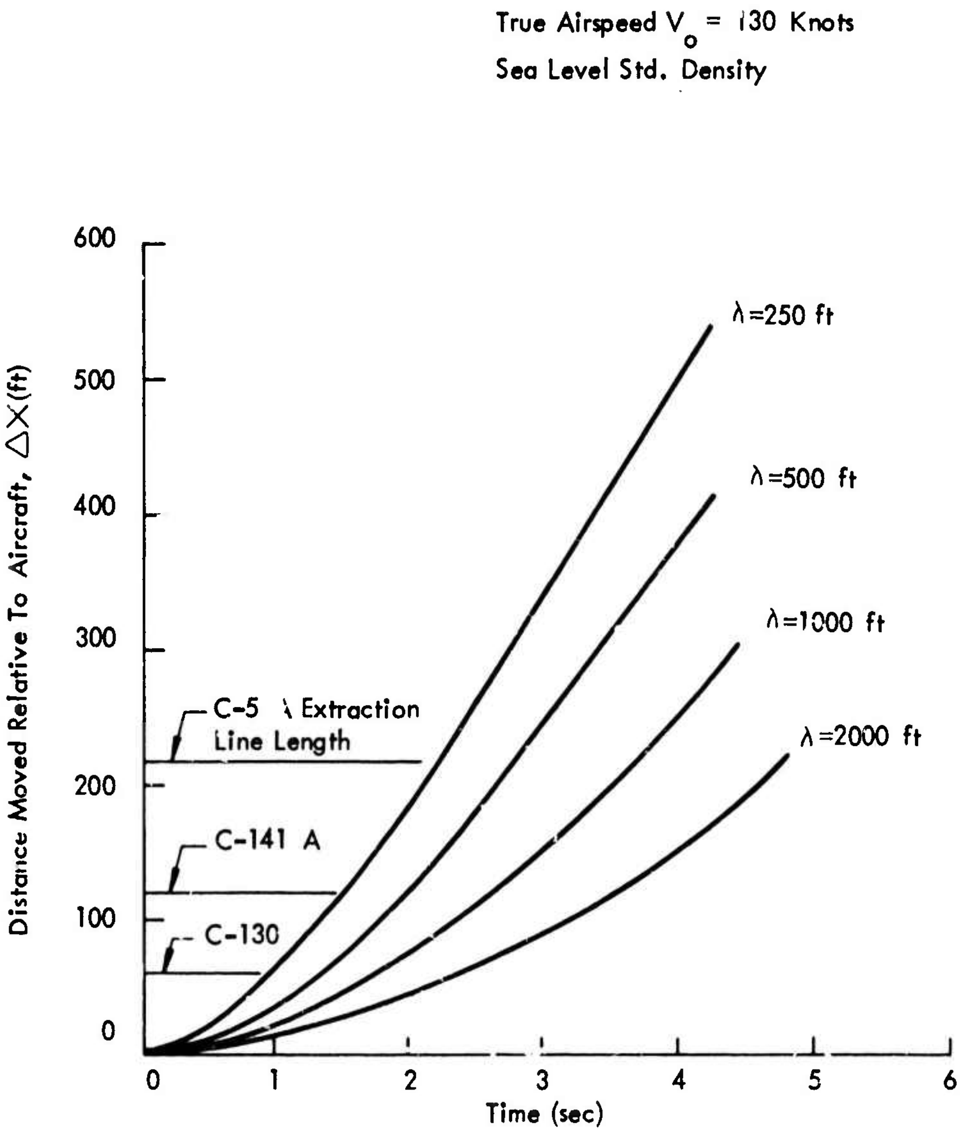


FIGURE 3-7.
SEPARATION DISTANCE VS TIME AS A FUNCTION OF SLOWING DOWN LENGTH FOR AN AIRCRAFT VELOCITY OF 130 KNOTS

True Airspeed V_o = 150 Knots
Sea Level Std. Density

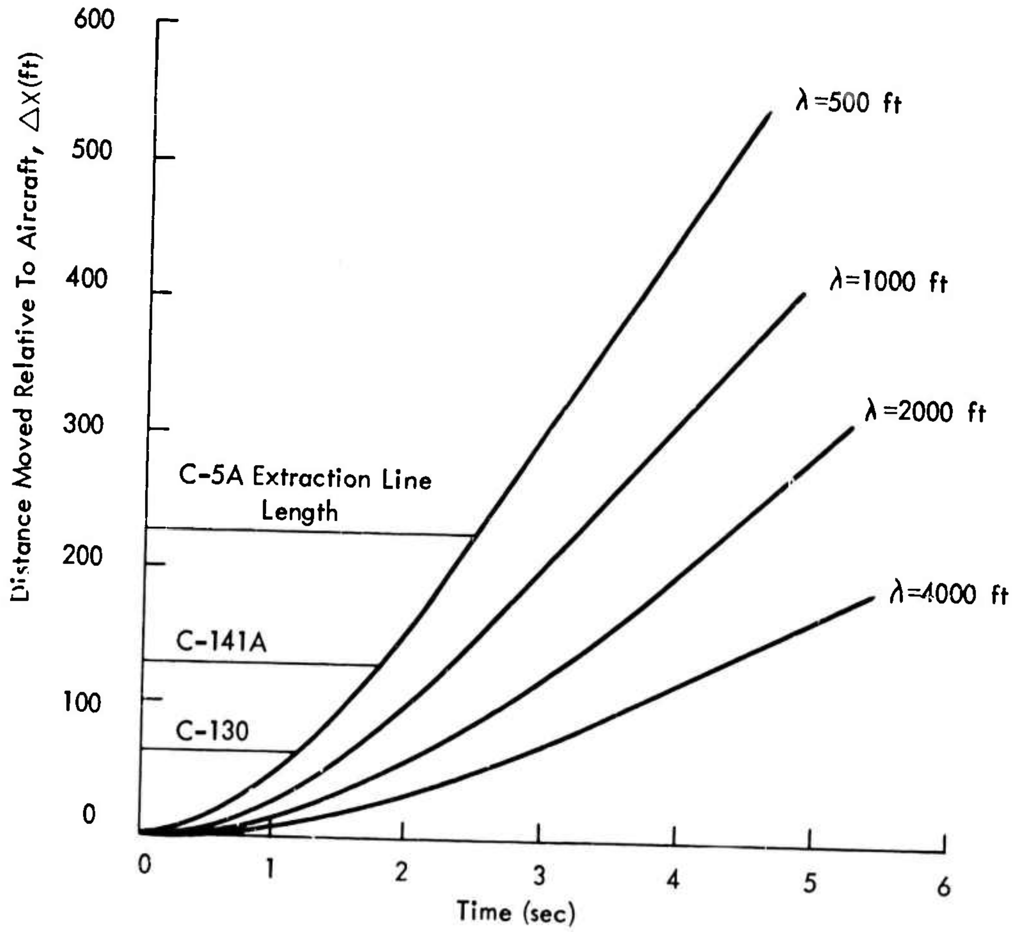


FIGURE 3-8.
SEPARATION DISTANCE VS TIME AS A FUNCTION OF SLOWING DOWN LENGTH FOR AN AIRCRAFT VELOCITY OF 150 KNOTS

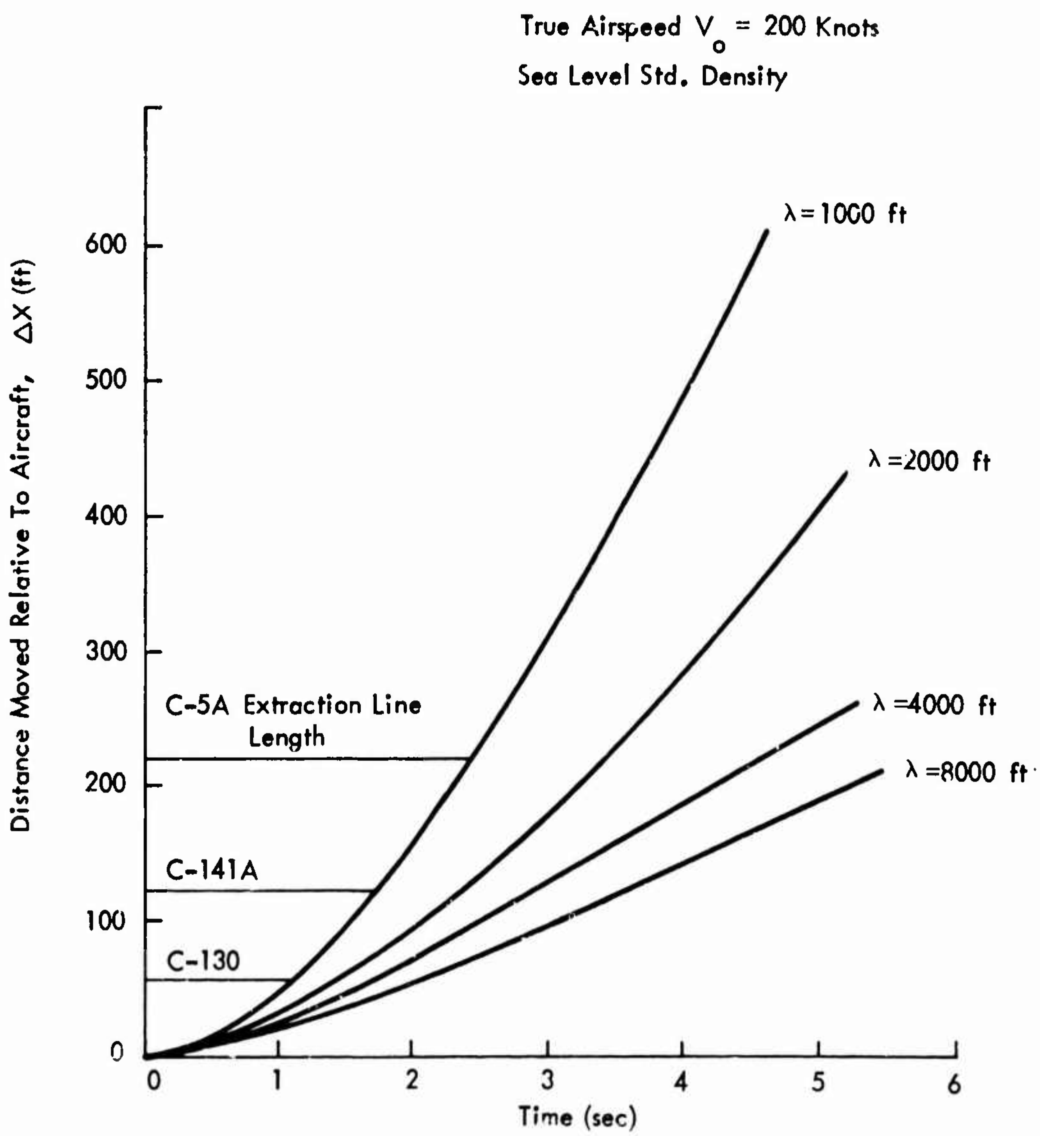


FIGURE 3-9.
SEPARATION DISTANCE VS TIME AS A FUNCTION OF SLOWING DOWN LENGTH FOR AN AIRCRAFT VELOCITY OF 200 KNOTS

Equations (7), (8), (9), and (10) may be used to obtain relative velocity between aircraft and a platform load as a function of relative distance moved by the platform for various aircraft speeds and parachute types.

The results obtained allow determination of the effects of several improvements to the standard airdrop system. Modifications to the standard system are analyzed in Section 4.1.2.

It is noted that in the above analysis the underlying assumption is that extraction force acts on the platform load during the entire extension of the extraction line. Actually, after force transfer, the force of the extraction parachute no longer acts to accelerate the load away from the aircraft, but aerodynamic drag on the extracted load provides a force in the same direction if not of the same magnitude.

The underlying assumption in the analysis becomes a better approximation for platform loads which are carried farther forward in the aircraft. In these cases force transfer occurs after more relative movement between the aircraft and load and the extraction line for the next sequential load is nearer to its full extension when force transfer occurs.

3.3 Other Calculated Results

A series of computerized ballistic trajectory studies were accomplished to observe the trajectory modification possible with variable time delayed reefing line cutters on the descent parachutes of platform loads. These calculations are summarized in Section 4.1.6 which describes an ACE concept for platform loads based upon variable reefing time trajectory control.

Generalized power requirements were calculated for personnel conveying systems installed in the drop aircraft. These calculations are summarized in Appendix D.

4.0 ACE SYSTEM CONCEPTS

During the course of the program many ACE System Concepts were considered. Some concepts were rejected after brief analyses based on their obvious inability to better the present airdrop systems. The concepts which were felt to merit further consideration are described in this section. For each of these systems, a discussion of the operation of the system is presented as is an estimate of system performance, and descriptions of factors influencing development cost, operational cost, logistical support requirements and details of the system installation in the aircraft.

4.1 Platform Load Concepts

Twenty ACE system concepts for Platform Loads were felt to have sufficient merit to warrant further consideration. These concepts are discussed herein as is the present Standard Airdrop System which is used for a basis of comparison.

4.1.1 Standard Airdrop System (SADS)

Descriptive Reference:

Reference 4

State of Development:

Currently Operational USAF Airdrop System

System Operation:

The Standard Airdrop System consists of a series of platform loads each of which is sequentially extracted from the aircraft by its own extraction parachute. As a particular platform exits the aircraft the application of the extraction force is transferred from the platform to the deployment bags containing the recovery parachutes. The extraction force then serves to remove the deployment bags, exposing the descent parachutes to the airstream causing them to inflate.

The load platforms used must be compatible with the Dual Rail Cargo Handling System installed in the three types of aircraft. The dual rail system provides lateral, vertical, and fore and aft restraint of the platform loads during transport operations, and provides guidance for the loads during the extraction process.

Fore and aft retention of the loads is provided by an indent-detent system which may either provide positive locking or locking of a platform against loads up to a preset load beyond which the platform is released. The detent release load is usually set to allow platform extraction when the extraction parachute force builds up to about one half the weight of the load.

Standard Airdrop System extraction equipment is shown in Figure 4-1. The extraction parachute for the aft-most platform is packed in its deployment bag and hung on the appropriate release receptable located in the aft end of the cargo compartment. One end of the extraction line is connected to the parachute by a metal link. The extraction line is then neatly flaked on the cargo floor and secured with 80 pound break ties. The other end of the extraction line is connected to the load with a force transfer device which may be either a fabric shear element or a mechanical linkage. Figure 4-1 depicts the fabric shear knife force transfer system. The fabric connector as shown will be severed as the load exits the aircraft by either of the two knives on static lines (two are used for reliability) that are attached to the anchor line cable installed inside the aircraft. The following series of events describes the normal airdrop sequence (Figures 4-2 and 4-3):

1. As part of crew procedures, aft restraint to the total load is manually removed except for a restraining force equivalent to approximately 1/2 g effected on each platform through spring loaded pressure locks. These pressure locks are set to release when the extraction parachute develops sufficient force during the inflation process.

2. The aircraft crew initiates the airdrop sequence by depressing the extraction parachute release button on the aerial delivery system (ADS) panel. The first extraction parachute(s) then falls into the air stream.

3. As the extraction parachute (contained in its deployment bag) develops drag it deploys the extraction line that has been stored on the aircraft cargo deck. Immediately following extraction line extension the bag closing ties are broken and the extraction parachute is deployed. As the extraction parachute inflates and overcomes the spring loaded locks the first load moves rearward with respect to the aircraft.

4. As the load passes the end of the cargo compartment or ramp edge, an extraction force transfer is made wherein the extraction parachute force is transferred to effect deployment of the recovery parachutes of the first load. Upon complete deployment and

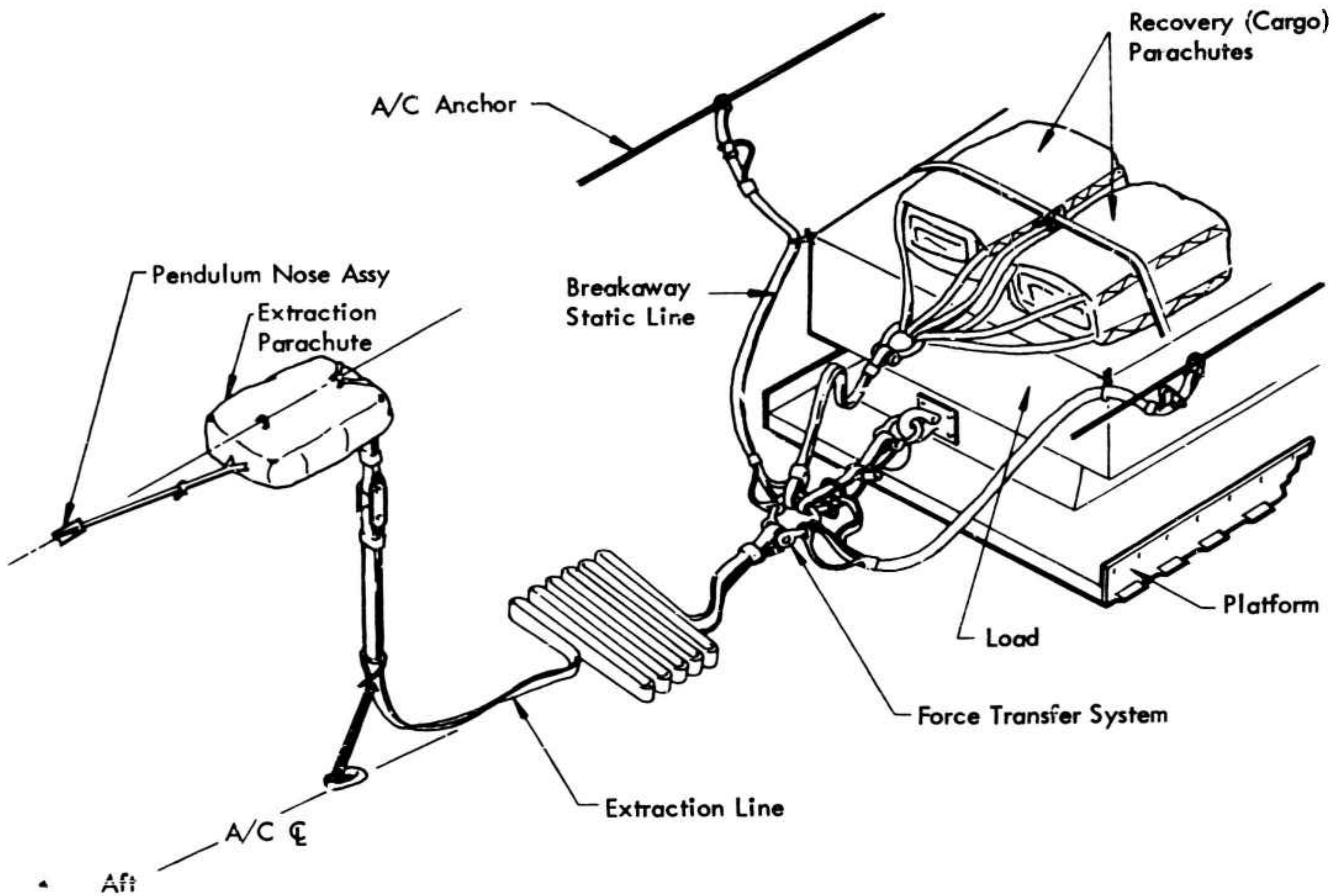


FIGURE 4-1
STANDARD AIR DROP EXTRACTION SYSTEM

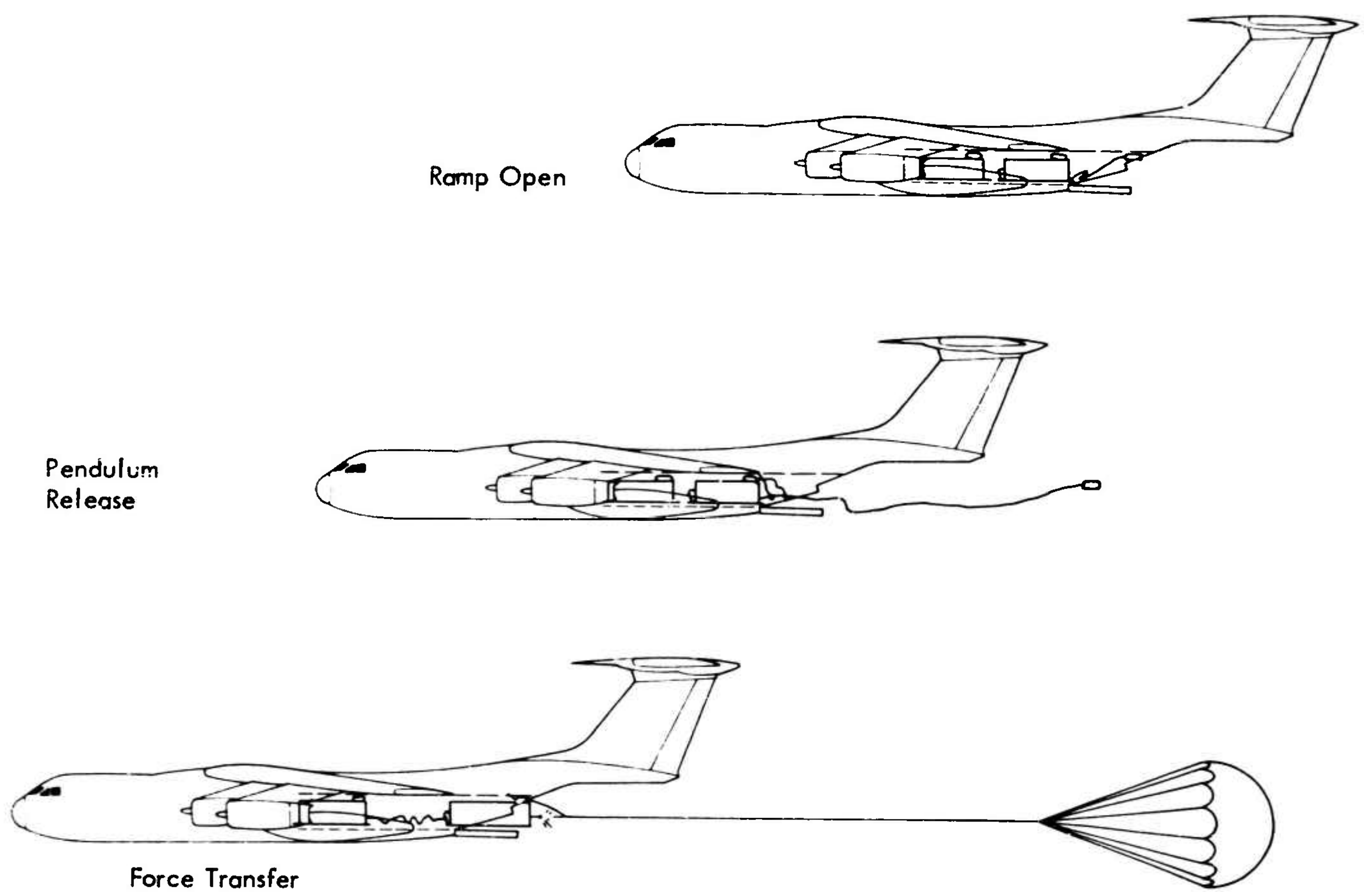


FIGURE 4-2
FIRST LOAD EXTRACTION CYCLE

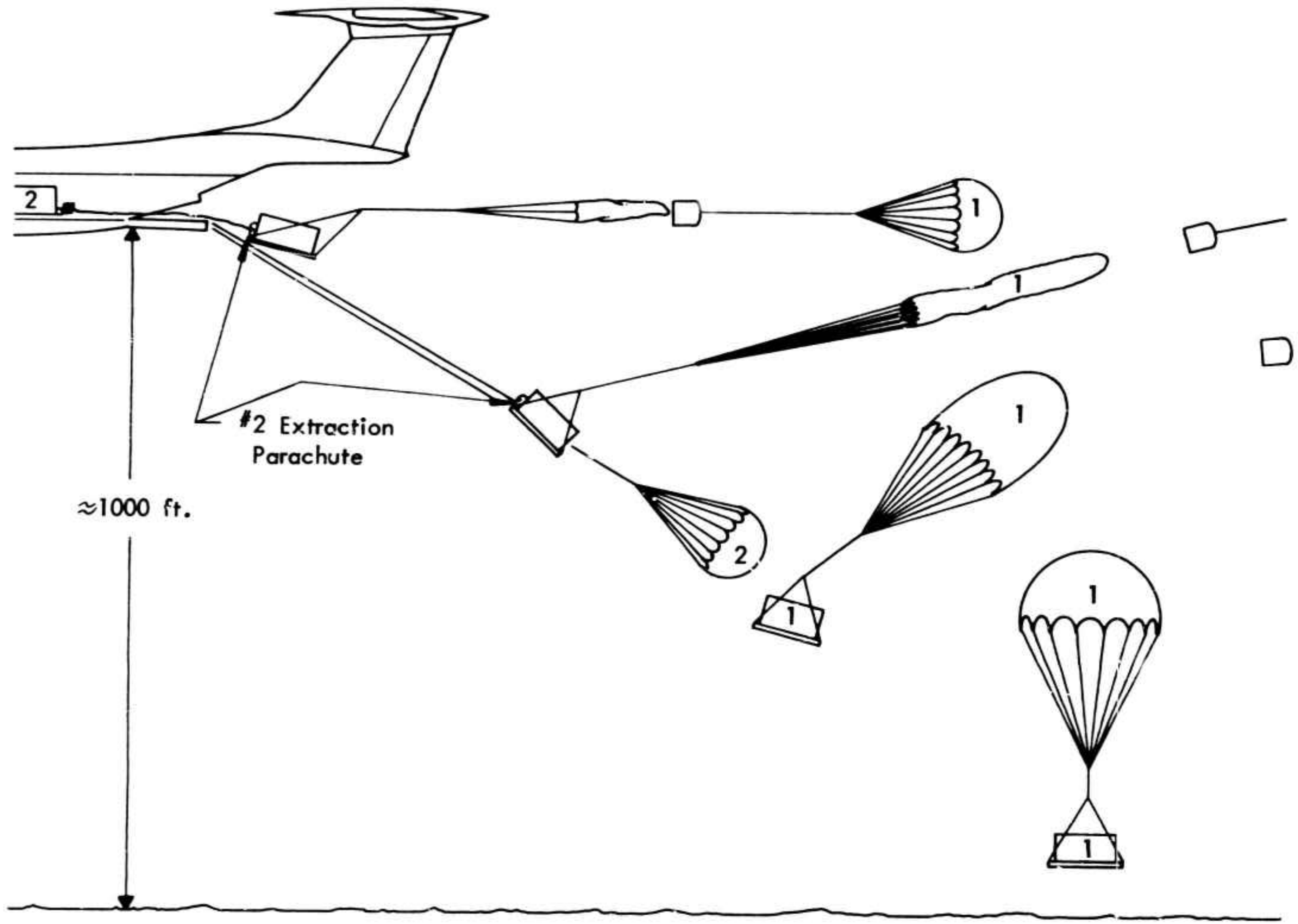


FIGURE 4-3.
FIRST LOAD RECOVERY & SECOND LOAD EXTRACTION

inflation of the main recovery parachutes, the load is in an equilibrium descent mode suitable for ground impact.

5. The extraction parachute for the second platform load is tied to the forward end of the first load with break cord and exits the aircraft with the first load while extending the extraction line for the second load. When the second extraction line is fully extended the second extraction parachute is pulled from its deployment bag and applies force to the second load through its force transfer coupling. Extraction of the second load is accomplished, and the second platform carrying the third extraction parachute from the aircraft allows the delivery process to continue until all platforms have been extracted.

Performance:

Standard airdrops from cargo aircraft, such as the C-130 and C-141, are made from altitudes of 800 to 1500 feet above the terrain and at airspeeds of 130 to 150 KIAS. Single and multiple loads of 2500 to 35,000 lbs. are possible.

The C-130 series carries about 35,000 lbs., the C-141A approximately twice that or 70,000 lbs. and the C-5A about four times the payload of a C-130 or about 210,000 lbs. Typical drop zone lengths required using the Standard Airdrop System (SADS) are the following (Reference 5):

Aircraft	No. of Sequential Loads	Individual Load Wt. (lb)	Total Airdrop Load (lb)	DZ* Length (ft)
C-130	4	8,000	32,000	3,520
C-141A	7	10,000	70,000	6,600
C-5A	15	10,000	150,000	16,500

Parameters influencing performance of this system will be investigated, and a performance standard for comparison of all other ACE systems to this system will be established.

* Distance from Green Light (i.e., includes distance traveled by aircraft during extraction of first platform).

System Installation:

System functioning is dependent upon use of the dual rail cargo handling system, extraction parachute pendulum assembly and overhead anchor cables installed in each of the aircraft types. Either reusable or expendable pallets may be used.

Power Requirement:

None.

Logistical Support:

Hardware items described above are generally carried in the aircraft. Additional items required include extraction and recovery parachutes, pallets, assorted rigging hardware and crushable cellular impact absorbtion material.

4.1.2 Improved Standard Airdrop System (ISADS)

Descriptive Reference:

This document.

State of Development:

Conceptual.

System Operation:

System operation is identical to that of the Standard Airdrop System. Some relatively small changes in equipment and operational technique, however, will significantly reduce the length of drop zone required for airdrop of sequentially extracted loads. The following procedural or equipment changes will produce reduction in drop zone length:

1. Airdrop loads should be rigged so that a total aircraft load consists of the fewest possible number of individual platform loads. Reduction in number of sequential loads is accomplished by dividing the total load so that longer, heavier platform loads are built up in place of many smaller loads.

2. Extraction parachutes should be selected to provide the highest acceptable extraction ratio for a given load. Acceptable accelerations on a load may be increased in some cases

above 1.5 g through load rigging techniques; and the extraction ratio achieved may be made to be closer to the maximum by choosing a larger parachute than required and reefing it to the necessary diameter. Increasing extraction ratios reduces extraction line extension time between sequential loads.

3. Extraction lines should be as short as possible consistent with normal extraction parachute operation. An extraction line length exists for each aircraft type and is used for each extracted load regardless of the initial position of the load in the specific aircraft. Line lengths may be tailored to load position so that the aft loads have shorter extraction lines than forward carried loads. Minimum extraction line extension time is then possible between sequential loads. The effect of shorter extraction lines may also be obtained by the method described in Section 4.1.5.

4. Extraction parachute opening times can be reduced by aerodynamic or mechanical inflation aids or by ballistic parachute opening devices. Reduced extraction parachute opening time reduces the distance over the ground which the aircraft covers during that part of the extraction cycle.

The four operational or equipment modifications indicated above each individually aid in drop zone length reduction. They may be used in any combination; and, through the combined effects of each change, substantial overall improvement is possible. Table 4-1 shows the 15 ISADS configurations possible through various combinations of the four individual improvements discussed above (the sixteenth configuration is the Standard Airdrop System with no improvement).

Performance:

Assuming for simplicity that all platforms loads which are to be dropped in sequence from an aircraft have similar extraction ratios and parachute opening characteristics, the length of drop zone (L_{DZ}) between the first and last load is approximately:

$$L_{DZ} = V_G (T) (n-1) \qquad (1)$$

V_G is the ground speed of the aircraft, T is the period of the drop cycle (i.e., the time between an event in the extraction of a platform and the same event in the extraction of the next load) and

System Configuration No.	Reduce No. of Loads	Max. Extraction Ratio	Short Extraction Line	Inflation Aided Extraction Parachute
ISADS 1	●			
ISADS 2	●	●		
ISADS 3	●		●	
ISADS 4	●			●
ISADS 5	●	●	●	
ISADS 6	●	●		●
ISADS 7	●		●	●
ISADS 8	●	●	●	●
ISADS 9		●		
ISADS 10		●	●	
ISADS 11		●		●
ISADS 12		●	●	●
ISADS 13			●	
ISADS 14			●	●
ISADS 15				●
SADS				

TABLE 4-1.
POSSIBLE ISADS CONFIGURATIONS

n is the number of platform loads. If T is taken as the time between one extraction parachute being fully inflated (immediately after platform release) and the next being fully open, then approximately:

$$T = t_e + t_o$$

where t_e is the time required for the aircraft and a platform load to be separated by the length of the extraction line connected to the next platform, and t_o is the time required for inflating of the next extraction parachute (the time between when the extraction line is fully extended and the parachute is fully inflated).

Changes which reduce the factors ($t_e + t_o$) or (n-1) in Equation (2) reduce the drop zone length.

$$L_{DZ} = V_G \; (t_e + t_o) \; (n-1) \qquad (2)$$

If the load normally carried on 4 eight-foot platforms in a C-130 is redistributed to be dropped on 3 twelve-foot platforms, the change in the factor (n-1) produces a total separation distance on the ground of 2/3 what it would have been. If the load from the 4 platforms is redistributed to be carried on 2 sixteen-foot platforms or a sixteen-foot platform and a 24 foot platform, the ground separation of the loads is 1/3 what it would have been if 4 loads were dropped. The consolidation of loads on to longer platforms, therefore, has a significant effect. The consolidation of loads, however, reduces operational flexibility.

The time for extraction line deployment, t_e, is affected both by extraction line length, and magnitude of deceleration of the platforms (extraction ratio). Using Figures 3-5, 3-6, and 3-7 from Section 3.2, it can be seen that t_e can be reduced by about 1 second if extraction ratios close to 1.5 are used rather than the minimum permissible extraction ratio. At 130 knots ground speed, the separation distance between individual airdrop loads is then reduced about 200 feet in using the highest rather than the lowest allowable extraction ratio. The saving of about 1 second occurs for all extraction line lengths of interest (i.e., 60 ft. for C-130, 120 ft. for C-141A and 215 ft. for C-5A). The percentage change in t_e is, however, quite dependent on extraction line length. Figure 3-7 also shows that cutting extraction line lengths in half also can reduce t_e by 0.5 to more than 1 second depending upon extraction ratio and the length of extraction line under consideration. Operationally, only the extraction lines for the aft most loads may be reduced in length.

The extraction parachute opening time t_o is normally about 1.0 second. This time may possibly be reduced by using mechanical or aerodynamic parachute inflation aiding devices. The use of a ballistic parachute opening device such as used in low altitude pilot escape systems on military aircraft would substantially reduce t_o.

The drop zone length L_{DZ} would be reduced by a factor of 2 if the factor $(t_e + t_o)$ could be cut in half. A reduction in the extraction cycle period of this magnitude seems quite possible. It is presently 4 to 5 seconds. Presently t_o is about 1 second and t_e is 2 to 4 seconds. A ballistic parachute deployment device might cause t_o to approach 0, while the improvements in t_e noted above are possible.

System Installation:

No aircraft modification is required for this ACE concept.

Power Requirement:

None

Logistical Support Requirements:

The following hardware changes would be necessary for implementation of improvements to the Standard Airdrop System:

1. Load platforms may have to be structurally stronger than the Army Type II platform if longer combined loads are dropped on a single platform (i.e., two vehicles per platform).

2. More care is necessary to select combinations of loads and extraction parachute sizes which provide the maximum permissible extraction ratio.

3. Extraction lines must be provided which are prefabricated for field adjustable to the length required for each individual platform location in the aircraft.

4. Any ballistic extraction parachute deployment device would require servicing at the time of parachute repacking.

Development Cost:

The following development costs may be incurred:

1. Flight test airdrop of combined loads would be required to qualify them for airdrop.

2. If extraction ratios are to be increased beyond 1.5, flight test would be required to prove the safety of this procedure.

3. Development costs would be involved in producing workable extraction parachute infaltion aids.

Operational Costs:

Operational costs should be equivalent to those for the Standard Airdrop System if airdrop platforms and parachutes are recoverable. If hardware is not recovered, cost of delivery by the improved system will be slighly higher due to loss of more expensive platforms and inflation aided extraction parachutes.

4.1.3 Multi-Extraction Parachute Subsystem (MEPS)

Descriptive Reference:

Reference 6

State of Development:

System was successfully tested in 1968 but no work is currently underway. For test data refer to Line Item Code (LIC) 5062, Naval Air Test Facility, El Centro Test Reports, February 1968 through August 1968.

System Operation:

The Multi-Extraction Parachute Subsystem (MEPS) employs a single extraction parachute to sequentially extract standard platform loads from the presently operational dual rail cargo handling system (Figure 4-4). The single extraction parachute is released by the extraction parachute pendulum mechanism, and, upon deployment, extracts the aft-most platform in the conventional manner. When the force transfer mechanism for the first load is activated by the two static lines, the descent parachutes for the first platform are deployed also in the conventional manner by force transferred through the deployment line. The MEPS concept differs from the Standard Airdrop System (SADS) in that an extraction line for the next load runs from the extraction clevis of the first load to the force transfer system of the second and subsequent loads over the tops of the loads. An extra length of extraction line is stowed between the loads. When the first stowed length of extraction line is extended, the second platform is pulled out of the aircraft, extraction force is transferred through the second deployment line to the second descent parachute and the extraction line to the

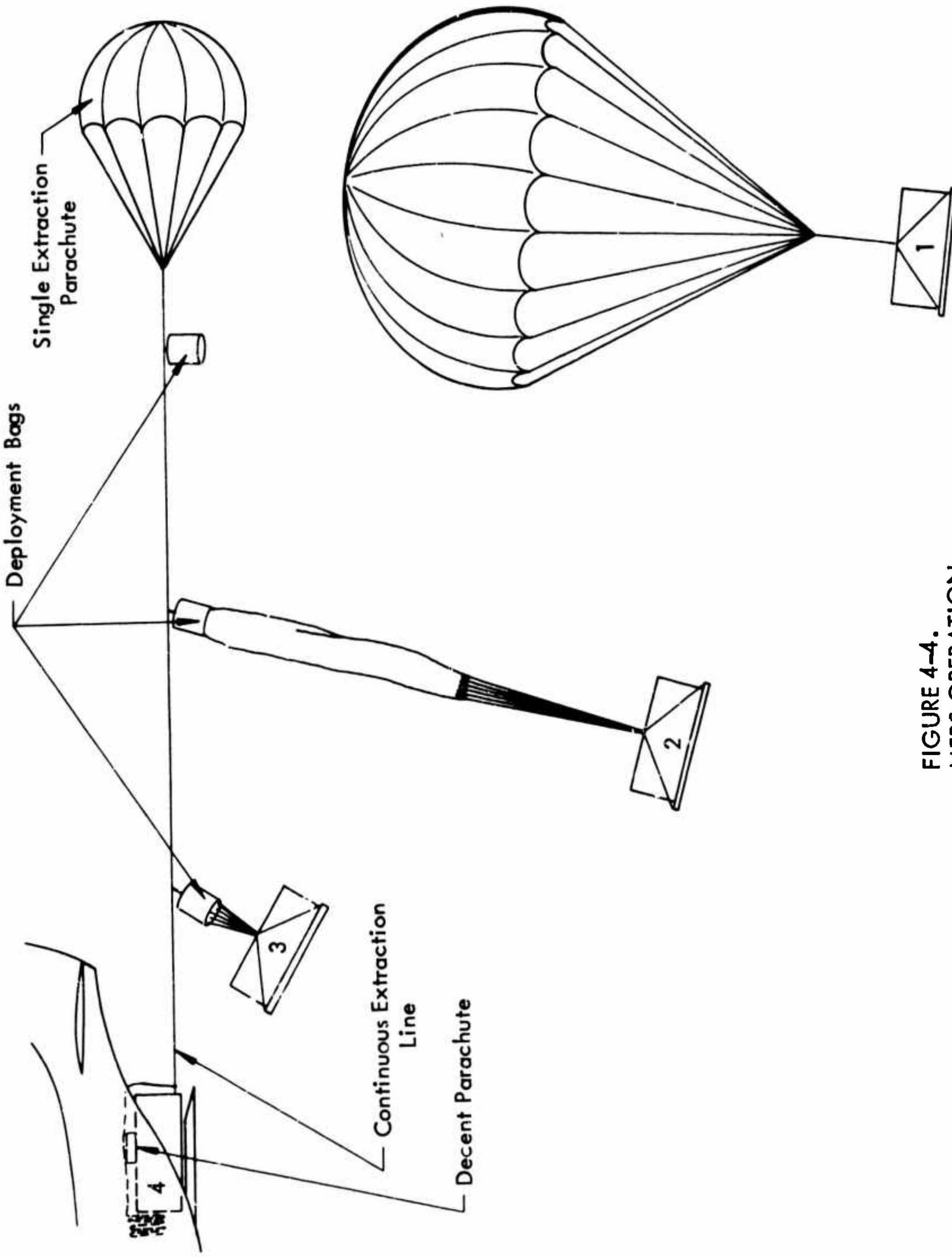


FIGURE 4–4.
MEPS OPERATION

third platform is extended. By means of this extraction line arrangement (Figure 4-5), a single extraction parachute does the work of several individual extraction parachutes (one for each platform as required by the Standard Airdrop System).

Because one extraction parachute (or one cluster) is used for all the platforms in an aircraft, less flexibility exists in selection of extraction force ratio, particularly if the masses of the several loads vary. The delivery of a mixed load of platforms with very largely differing platform load masses may not be possible with the MEPS concept. Heavier loads may, however, be placed forward in the aircraft and lighter loads aft. This arrangement will allow exit velocities of different weight loads to be similar with the necessarily different extraction ratios.

System Performance:

Much of the drop zone length required for the Standard Airdrop System is due to the distance the aircraft travels during the opening times of the sequentially deployed extraction parachutes attached to the individual platform loads and the time required for subsequent extraction line extension due to relative motion between an extraction load and the aircraft. With the MEPS technique the drop zone length is reduced through the use of a single extraction parachute. Actual drop tests of sequential loads have demonstrated ground impact points of the first two platforms in a sequence to be generally 250 to 300 feet apart, with some very much closer (Reference 6). However, as the number of loads in a sequence increases the separation between adjacent impact points become larger but remains smaller than that resulting from conventional techniques. Overall the drop zone length is reduced by 1/4 to 1/3 of the length required for the same sequential platform loads deployed using standard airdrop techniques.

System Installation:

No aircraft modification is required to employ the MEPS technique. The concept involves a change in load rigging procedures and eliminates all but one extraction parachute. Any type of airdrop cargo pallet compatible with the dual rail system may be employed. A special long extraction line is required. A temporary covering of the aft - end of the ramp floor may be required to prevent abrasion damage to the extraction line in that the extraction parachute tends to descend below the aircraft during the extraction process.

Power Requirement:

None.

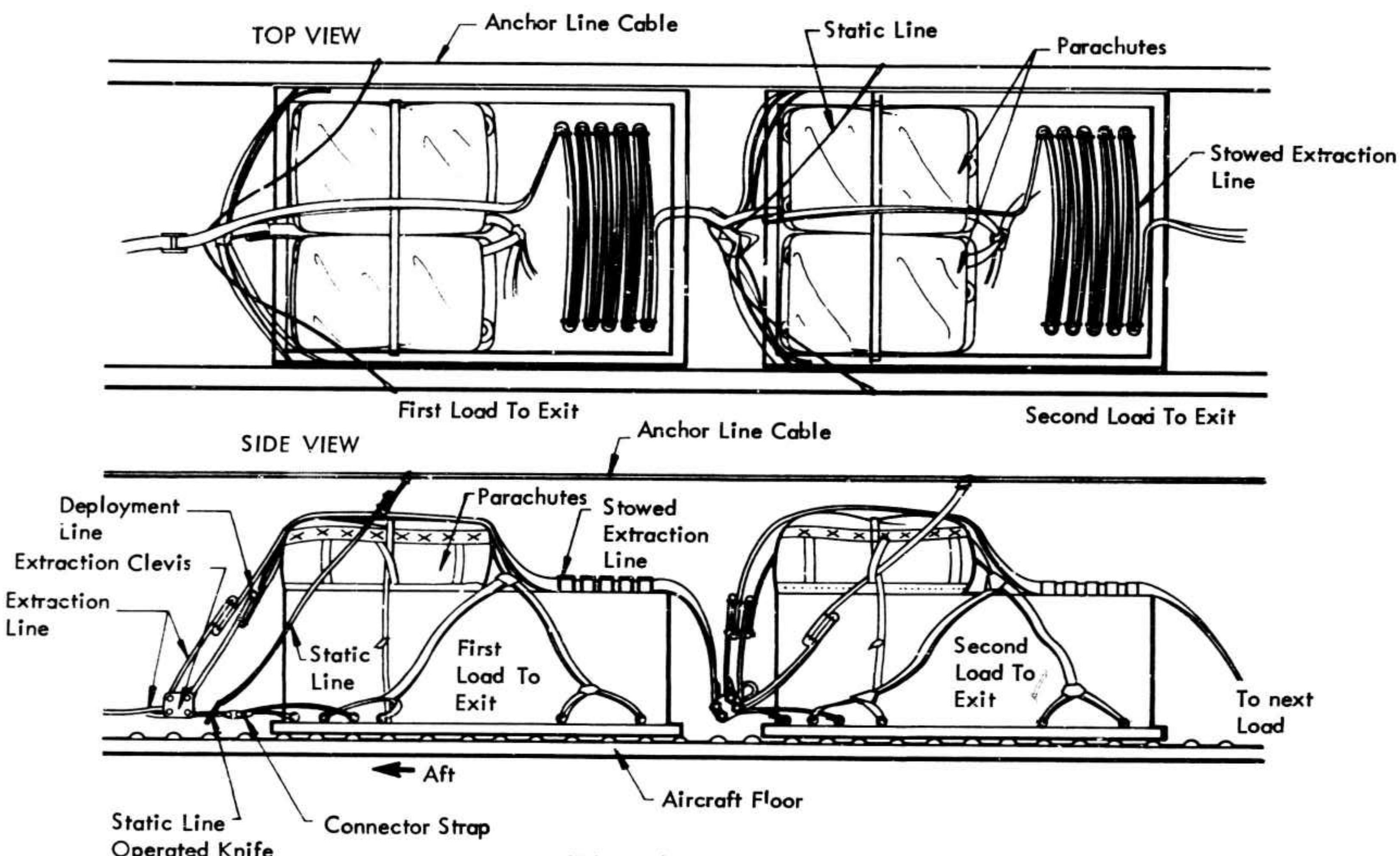


FIGURE 4-5.
MEPS RIGGING

Logistical Support Requirement:

A new extraction line is required. The line is recoverable with the extraction parachute and series of descent parachute deployment bags.

Development Cost:

The development cost of the system appears minimal. All necessary components exist and are operational. Feasibility has been demonstrated through actual drop tests. Development work appears necessary to perfect the rigging techniques operational procedures.

Operational Costs:

Operational costs appear lower than for the standard system due to the use of fewer extraction parachutes. Recoverable or expendable load pallets may be used.

4.1.4 Rapid Extraction System (RES)

Descriptive Reference:

Reference 7.

State of Development:

First system test is planned to be conducted in 1973 by the El Centro Parachute Test Facility for the Equipment Development Branch, Delivery and Retrieval Division, Directorate for Crew and AGE, ENCDE, ASD, Wright-Patterson Air Force Base, Ohio.

System Operation:

The Rapid Extraction System employs a cluster of extraction parachutes to extract a train of platform loads all mechanically linked together. The extraction force is applied directly to the aft pallet until the tandum load exits the aircraft. The force transfer mechanism then applies the extraction force to the deployment bags of the descent parachutes. The linked-together tandum load is connected to the descent parachute risers through a special suspension sling and cluster clevis. The total tandum load descends as a single unit.

Since the extraction force is transmitted through the pallets and connecting links, the pallets used must be the Metric modular extruded aluminum pallets (Air Force) or equivalent. The Army Type 2 expendable blasa wood filled pallets do not possess sufficient strength for the application.

The extraction process is identical to that used in the operational LAPES system with all extraction hardware items being those used for LAPES with the exception of the pallet connecting links. Simple, straight connecting links replace the LAPES links.

All three aircraft (C-130, C-141, C-5A) can airdrop single loads of up to 35,000 lbs. Considering aircraft payload capability, the entire airdrop load carried by a C-130 could be extracted at one time. Two groups of inter-connected loads could be delivered sequentially from the C-141 while four groups of linked loads could be delivered from the C-5A.

Operation of the Rapid Extraction System is illustrated in Figure 4-6.

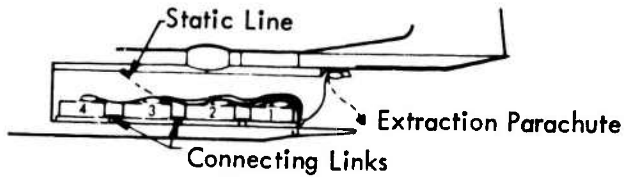
System Performance:

The entire airdrop load of a C-130 (35,000 lbs.) would land intact (or with no dispersion). In contrast, 4 - 8,000 lb. loads sequentially dropped using the standard method would require a drop zone of about a 3,000 ft. length. A C-141 conventionally dropping 7 - 10,000 lb. loads would require about 6,000 ft. of drop zone length. The Rapid Extraction System dropping two tandum loads of 35,00 lb. each should require a drop zone of about 2,500 ft. A C-5A conventionally dropping 15 - 10,000 lb. loads requires a drop zone length of about 14,000 ft. If 4 - 35,000 lb. Rapid Extraction System loads were dropped from the C-5A, about 4,000 ft. of drop zone length would be required.

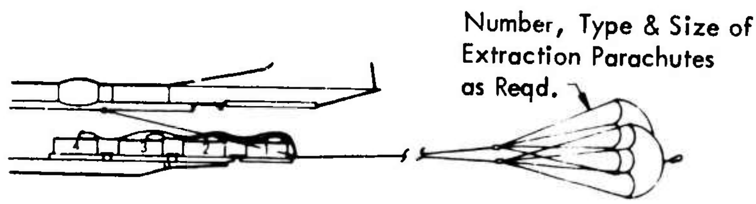
System Installation:

No aircraft modification is required. Aluminum structural load platforms such as the Metric modular platforms used for LAPES are required, and special interconnecting links must be provided. Extraction system parachutes, force transfer system hardware, and descent parachutes and deployment hardware are of the type used in the Standard Airdrop System. A new suspension sling and suspension techniques must be developed to stabilize and support the tandum loads during descent parachute inflation.

LOADS ABOARD AIRCRAFT



EXTRACTION



FORCE TRANSFER

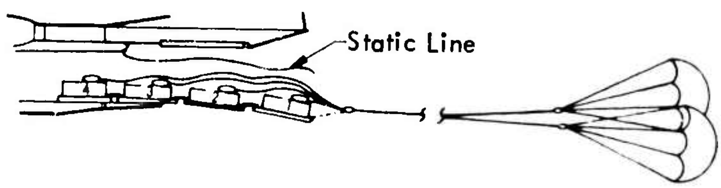


FIGURE 4-6.
RAPID EXTRACTION SYSTEM OPERATION

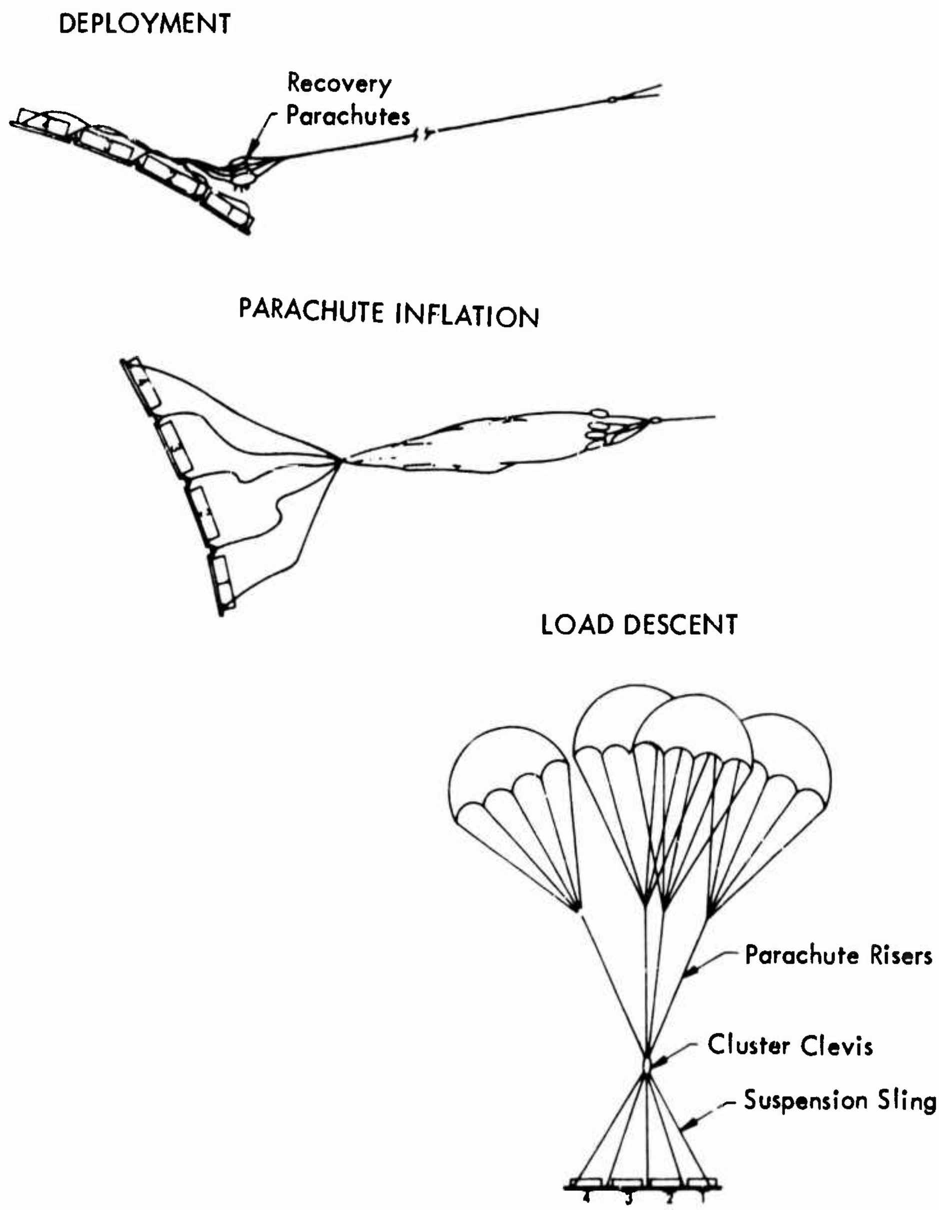


FIGURE 4-6. (Continued)

Power Requirement:

None.

Logistical Support Requirement:

Only one extraction parachute (or cluster) is used per tandum load reducing the number of extractio" parachutes required. Expendable platforms (low strength) may not be used.

Development Cost:

It is expected that the Rapid Extraction System method of delivery will not require appreciable hardware development. Much of the hardware for the extraction of tandum loads is presently used for LAPES air delivery of platform loads. A substantial development effort may be required to experimentally determine how to stabilize the tandum load during descent parachute deployment.

Operational Cost:

Low cost expendable Army Type 2 platforms cannot be used with this system. This may be significant in situations where the platforms are not recovered. Conversely, fewer extraction parachutes would be lost in similar situations than for the standard airdrop system.

4.1.5 Extraction Parachute on Recovery Parachute (EXPOR)

Descriptive Reference:

Reference 8.

State of Development:

The system has been independently tested and approved by the Air Force Flight Test Center (AFFTC) and was used during U. S. Army C-5A Airdrop Capability Evaluation Flight Tests at Fort Bragg.

System Operation:

System operation is essentially the same as that of the Standard Airdrop System (SADS) with the following exception. Placement of packed extraction parachutes for loads subsequent to the first load extracted is changed. On the standard system the extraction parachute for a platform is carried on the forward end of the platform preceding it in the sequential extraction process. On the EXPOR system, the extraction parachute for a platform is carried on the deployment bag of the recovery parachutes for the preceding load. Extraction line extension is caused by motion of the recovery parachute deployment bag after force transfer occurs, rather than by actual platform relative motion away from the aircraft. Functioning of the system is illustrated in Figure 4-7.

Performance:

In an extraction cycle, after force transfer occurs, the deploying recovery parachute and its associated deployment bag move away from the aircraft much more quickly than the platform to which it was tied before the force transfer event. When the extraction parachute for the next platform is attached to the recovery parachute deployment bag of the previous load, extraction line extension time is much reduced For the standard system, extraction line deployment times are approximately 2 sec. for the C-130 (60 ft. extraction line), 3 sec. for the C-141 (120 ft. extraction line) and 4 sec. for the C-5A (215 ft. extraction line) at 130 knots air speed. These times should be substantially reduced resulting in a reduced extraction cycle period and smaller ground dispersion. Ground separation distance of loads should be reduced by about the product of the aircraft ground speed and the time saved per extraction cycle.

Flight tests of sequential airdrops from C-5A aircraft using the standard rigging method have shown ground separation distances to be between 1100 and 1300 ft. (References 7 and 9). The average ground separation distance of 5 sequential loads dropped using the EXPOR rigging technique is shown in Reference 8 to be 1075 ft. Separation distances of as low as 840 ft. were reported for the EXPOR system in Reference 9.

It appears that extraction cycle period is reduced by about 1 sec (220 ft. ground distance at 130 knots) for sequential extraction from the C-5A. It is felt that a similar reduction in ground distance between sequential loads from the C-130 and C-141 would be realized.

System Installation:

No aircraft modification is required.

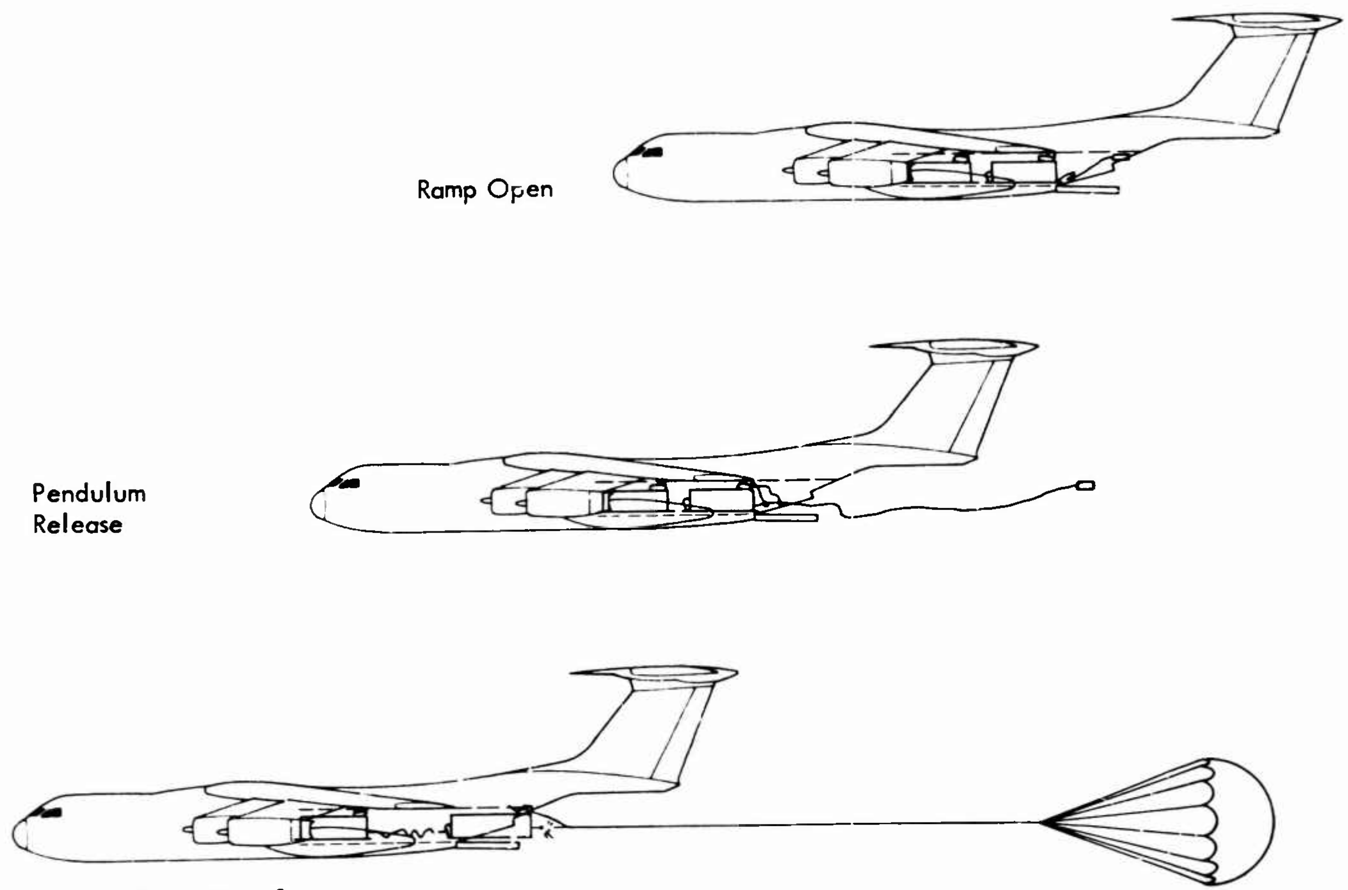


FIGURE 4-7.
EXTRACTION PARACHUTE ON TOP OF PACKED RECOVERY PARACHUTE

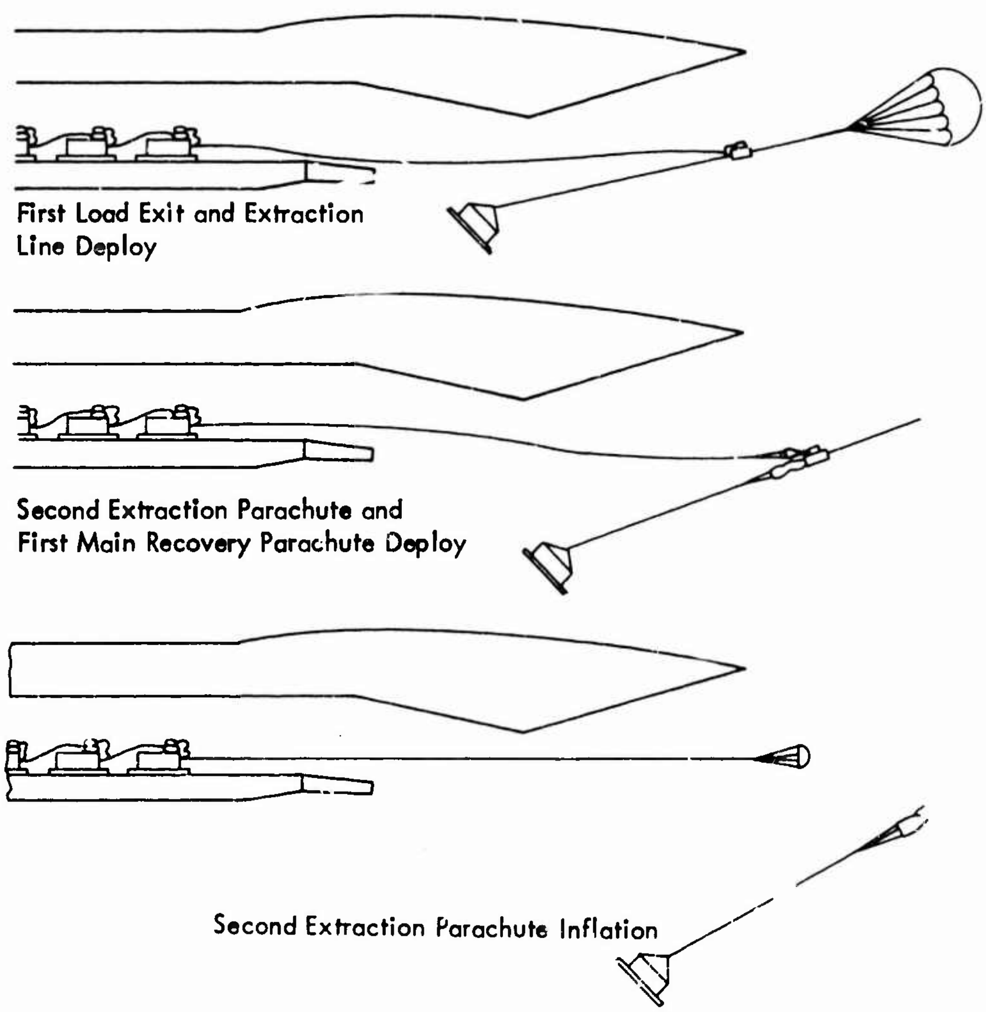


FIGURE 4-7. (Continued)

Power Requirement:

No aircraft power is required.

Logistical Support Requirement:

Platform load rigging material, extraction parachute system and recovery parachute system hardware are the same as used in the Standard Airdrop System.

Development Cost:

Additional flight testing is required to prove techniques which will positively preclude interference between deploying extraction parachutes and the preceding platform load (extraction parachutes deploy aft of the load upon which they are carried). Some interference of this nature was observed in the flight test described in Reference 9.

Operational Cost:

Operational cost is the same as for the Standard Airdrop System.

4.1.6 Variable Reefing Trajectory Control (VRTC)

Descriptive Reference:

This Document.

State of Development:

Conceptual, however required hardware exists.

System Operation:

System operation is identical to that of the Standard Airdrop System with the exception that the first platforms extracted are equipped with descent parachutes which are reefed to minimum diameter for several seconds after deployment. The latter platforms extracted have descent parachutes which are allowed to fully inflate as fast as possible, and the ground dispersion of the loads is reduced because of the different trajectories followed by the first and last loads out. Reefing the first loads out allows them to translate farther horizontally due to their higher ballistic density early in their descent. High drag on the latter loads occurs early and they have less horizontal motion. The overall effect is to shorten the drop zone length from the ground position of the first to last load extracted. Loads extracted between the first and last loads would have reefing cutter delay times adjusted to cause their trajectories to fall between those of the first and last loads (Figure 4-8).

System Performance:

It may be seen from Figure 4-8 that the reduction in drop zone length achieved is the difference in horizontal distance traveled from extraction to ground impact for the first and last load out. This distance may be determined by computing trajectories for a platform load with and without an initially reefed main parachute. The reefing cutter time delay must also be determined from trajectory analysis to determine the appropriate delay time to be used. For the purpose of preliminary evaluating performance, a two degree of freedom, point mass trajectory program (Reference 10) was used. The computer program was modified to calculate trajectories for a point mass which has a drag area which increased linearly with time during the opening time of the disreefed parachute. The program also was given the ability to provide a variable time delay for the reefing line cutter.

Figure 4-9 shows calculated trajectories for a platform load with reefing cutter time delays of 0, 5 and 10 seconds for the following input parameters:

Aircraft true airspeed	130 knots (220 ft/sec)
Extraction velocity relative to aircraft	40 ft/sec
Extracted load initial velocity	180 ft/sec
Aircraft altitude (MSL)	2500 ft.
Load terminal velocity with reefed descent parachutes	180 ft/sec
Load terminal velocity with parachutes fully inflated	20 ft/sec
Parachute opening time	7 sec.
Drop zone wind	0
Drop zone elevation (may be 0 - 2500 ft.)	Not specified

The calculations are for a generalized platform load with ballistic characteristics specified only in terms of terminal velocities at sea level for the conditions of reefed and fully open

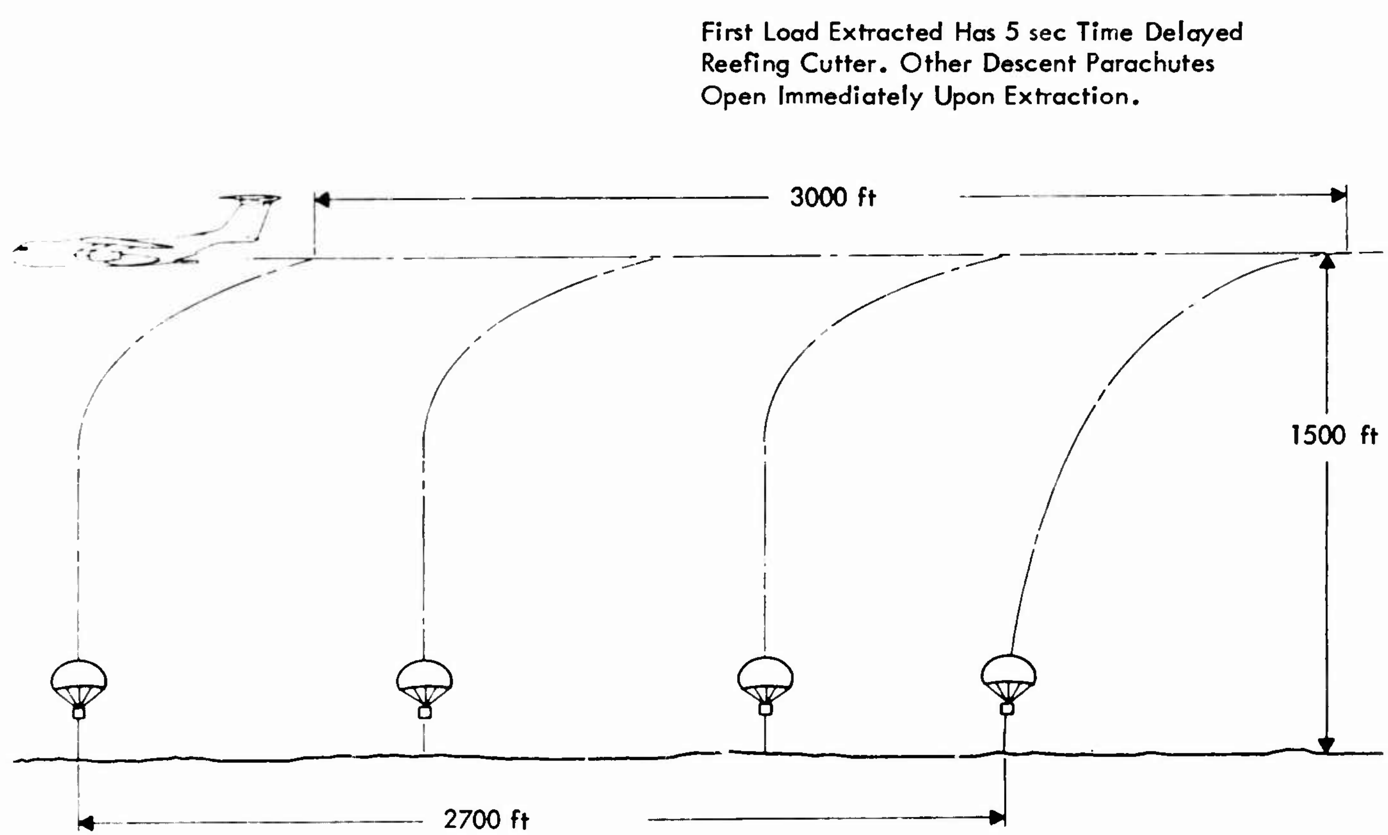


FIGURE 4-8.
TRAJECTORY CONTROL BY TIME DELAYED
DEREEFING OF DESCENT PARACHUTES

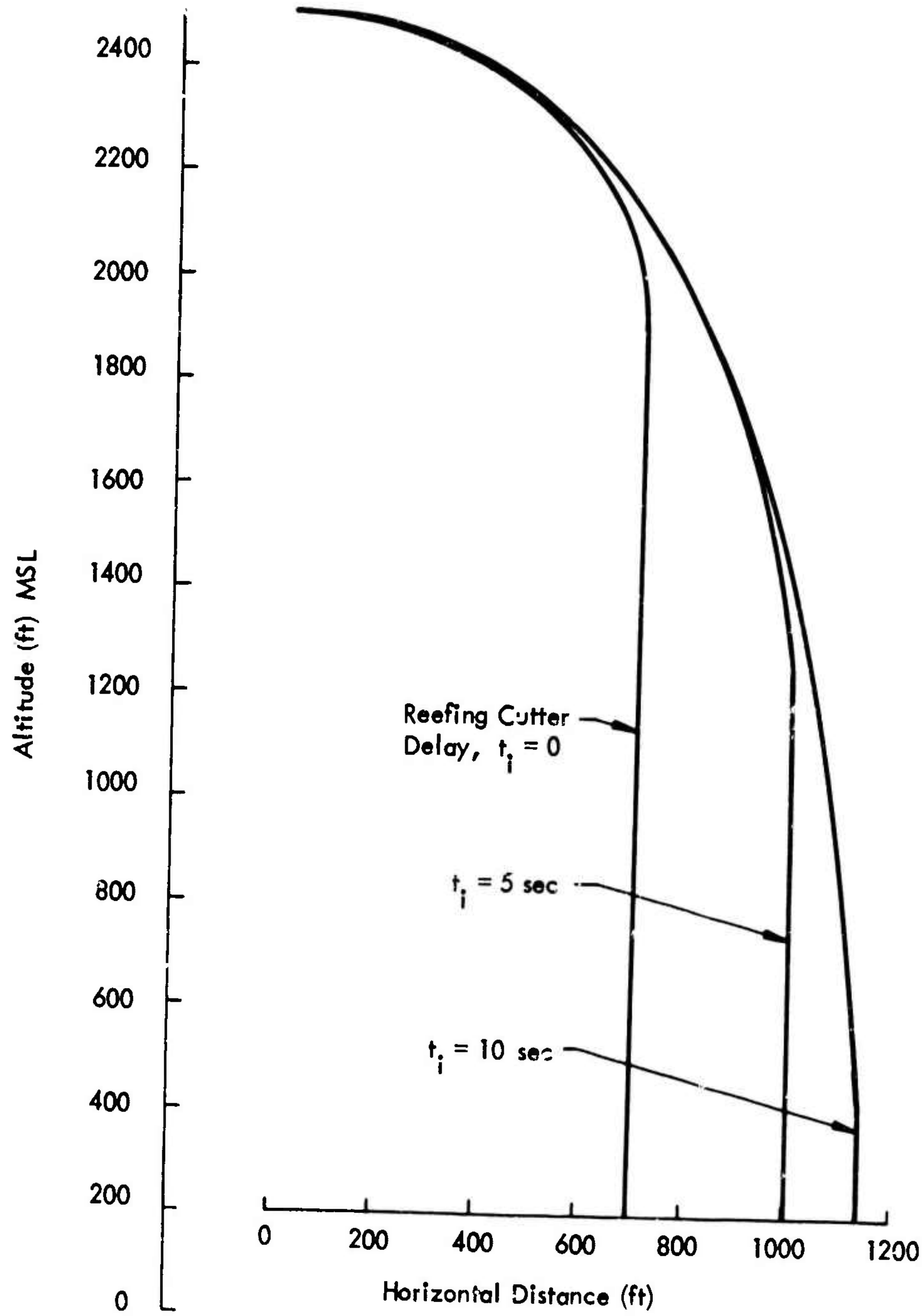


FIGURE 4-9.
EFFECT OF REEFING LINE CUTTING
DELAY ON HORIZONTAL DISTANCE
FLOW DROP TO GROUND IMPACT

descent parachutes. Reference 11 describes a technique with which platform loads were extracted with reefed G11A descent parachutes. Reefing lines as short as 25 ft. were used successfully to provide extraction ratios of 0.75 to 1.5 at typical aircraft drop speeds, hence the selection of 180 ft/sec for terminal velocity of platform loads with tightly reefed main parachutes.

Figure 4-9 shows that for a 1500 ft. AGL drop (DZ elevation 1000 ft. MSL) the distance between ground positions of the first and last load may be reduced by 300 ft. if the first load extracted is tightly reefed for 5 seconds after extraction. If the airdrop were made from 2300 ft. AGL (DZ elevation 200 ft. MSL) a 10 second reefing cutter delay could be used, and the ground distance from first to last load is reduced by 440 ft. from that of the Standard Airdrop System.

The ground distance saved is a constant and independent of the number of sequential loads dropped. For a C-130 dropping two sequential loads, the ground distance between them can be reduced 30 to 50%. For a stick of four sequential loads, a 300 to 450 ft. reduction in total ground separation of the first and last load is only 10 to 15% of the total ground length without reefing of the first descent parachute. For a larger number of sequential loads dropped in one pass (such as from a C-141 or C-5A) the percentage savings is insignificant.

It is apparent that real savings in drop zone dispersion is achieved by reduction in the extraction cycle of each sequentially extracted item. The reduction is proportional to the product of the number of sequential platforms and the time saved per cycle. VRTC by itself only has the effect of reducing the drop zone by the amount saved with one time delayed dereefed parachute. It is, however, amenable to employment with any ISADS scheme or with MEPS to provide additional drop zone dispersion reduction with little increased complexity or cost. VRTC is also a technique available to provide a non-linear drop zone dispersion pattern.

System Installation:

No aircraft modification is required.

Power Requirement:

None.

Logistical Support Requirement:

System hardware is identical to that for the Standard Airdrop System with the exception that short reefing lines (25 ft.) must be installed with 5 or 10 second delay reefing line cutter on the G11A descent parachutes of the first load extracted.

Development Cost:

Minimal development cost but flight test required.

Operational Cost:

Same as the Standard Airdrop System.

4.1.7 Extraction Engine System (EES)

Descriptive Reference:

This Document.

State of Development:

Conceptual.

System Operation:

Platform loads are ejected from the aircraft due to force applied by a prime mover installed in the aircraft specifically for this purpose rather than by an extraction parachute. Descent parachutes are static line deployed for each platform. No particular type of extraction engine is specified at this time. Internal combustion engines or electric motors may be considered. The force applied to the platform load could be by means of a cable/pully system. The concept is illustrated in Figure 4-10.

System Performance:

System performance is expressed in terms of the period of the sequential extraction cycle which is achieved. The Standard Airdrop System has an extraction cycle period of 4 to 5 seconds. To be attractive, an improved system should have a period of about 2 seconds.

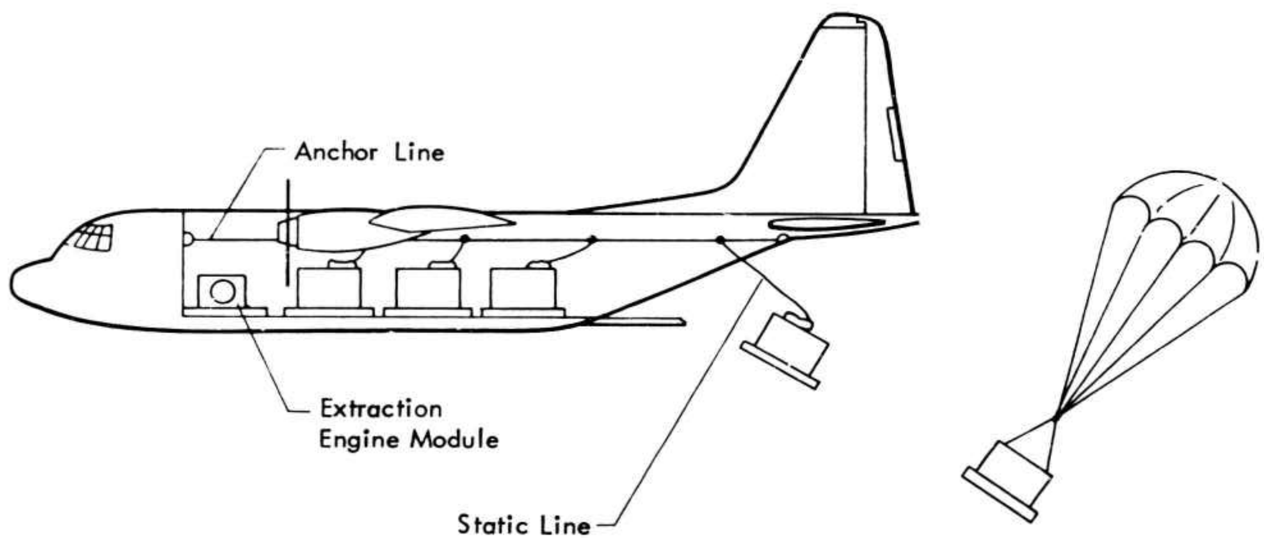


FIGURE 4-10
EXTRACTION ENGINE SYSTEM

System Installation:

The prime mover (or extraction engine) would be mounted on a short power module platform which is in turn held by the dual rail cargo handling system in the forward-most area of the cargo compartment. Cables used to eject the platform loads could run along the sides of the platform loads or in the space between the bottoms of the platform and the aircraft cargo bay deck (i. e., between the rollers). A control panel for the system could be installed on the engine platform.

Power Requirement:

The extraction engine must accelerate individual platform loads to a velocity of about 30 ft/sec relative to the aircraft at an average acceleration of about 1.0 g. The M2A1 105mm Howitzer is the heaviest Division Ready Force (DRF) load at 8600 lb. If an extraction engine is sized to eject loads of this size sequentially at a cycling period of 2 seconds, the peak power required (excluding friction) is 470 horsepower which occurs instantaneously as the platform relative velocity reaches 30 ft/sec. The time average power is about 80 horsepower. If an energy storage device is used such as a fly wheel or compressed gas storage system, an engine with a continuous power output of about 150 horsepower could probably be used. This power requirement is much too large to be supplied from the aircraft electrical system. An internal combustion engine therefore is indicated. A gas turbine/flywheel system with associated clutches and hardware seems a good choice. A solid propellant gas generator used with a turbine is another interesting possibility.

Logistical Support Requirement:

The extraction engine module must be made available to accomplish airdrop operations. If carried in the aircraft at all times when the possibility of using it exists, the forward 3 - 4 ft. of the cargo bay would be unusable for carrying payload.

Development Cost:

Development of this system seems straightforward. The prime mover and energy storage system must be integrated and modularized, and a cable/pully system developed to apply the accelerative force sequentially to the platform loads.

Operational Cost:

The cost of extraction parachutes is saved over that of the standard system; however, continuing installation and maintenance costs for the power module and cable system will be incurred.

4.2 Personnel Airdrop System

Seven (7) ACE System Concepts for personnel airdrop were felt to have sufficient merit to warrent further consideration. These concepts are discussed herein as is the Standard T-10 Parachute Personnel Airdrop System which is used as a basis for comparison.

4.2.1 Standard Personnel Airdrop System (SPADS)

Descriptive Reference:

Reference 12

State of Development:

Currently Operational U. S. Army/U. S. Air Force Personnel Airdrop System.

System Operation:

The standard system for personnel airdrop is the T-10 static line deployed parachute assembly used by jumpers in two sticks simultaneously exiting from two side jump doors of the several aircraft types considered. Procedural details for the standard system differ slightly with aircraft type. For the purposes of this study, the methods described in reference 12 are taken as standards for comparison when required. Additionally, preceding each line or stick of troopers assigned to a jump door are two door bundles each of which may weigh up to 500 lbs. These items must be manually pushed from the aircraft and be clear before actual troop exits begin.

The nominal fully loaded weight of an individual trooper is taken as 250 lbs. In addition to carrying their regular equipment, ten paratroopers per aircraft will be required to carry Parachute Accompanying Equipment Bags which can weigh up to 100 lbs.

System Performance:

The Standard Personnel Airdrop System (SPADS) drops 64 parachutists from the C-130, 123 from the C-141 and approximately 200 from the C-5A. Troopers jump at nominally 1.0 second intervals at each of the two exits. Additionally, 4.0 seconds is required to manually push the door bundles out of the aircraft before jumping can commence. In a no wind condition with an aircraft true airspeed of 130 knots the following drop zone lengths are required to contain the door bundles and paratroopers:

Aircraft Type	DZ Length (ft)
C-130	7,800
C-141	14,400
C-5A	23,000

The drop zone length requirements for the same flight conditions but with no door bundles are:

Aircraft Type	DZ Length (ft)
C-130	7,000
C-141	13,500
C-5A	22,000

The effect of door bundles on total drop zone length is seen to be small with the Standard Personnel Airdrop System, and these items by themselves should not unduly restrict the development of a personnel airdrop system.

System Installation:

A personnel airdrop kit and other special provision for paratroopers exist for each aircraft type. Special items for accommodating paratroopers include the following:

Dual anchor line installation

Two side jump doors

Jump platforms

Jump door spoilers

Cockpit to jump door position intercom system

Light signal system

Static line retrieval wench system

Foldable (stowable) seating provisions for paratroopers

Power Requirement:

None.

Logistical Support:

In addition to provisions of the above aircraft installed items, individual, well maintained T-10 parachutes and other jump gear must be supplied for each trooper.

4.2.2 Northrop Egress Subsystem

Descriptive Reference:

Reference 13.

State of Development:

Conceptual.

System Operation:

Parachutists are aided to the two side jump doors on both the C-130 and C-141 aircraft by means of moving, fore and after running, overhead egress cables which have hand grips at even intervals. One cable is associated with each door. The cable speed serves to pace the jumpers to the doors and the cables provide some stabilizing support and a slight motivational force (less than 20 lbs. per man). Handle spacing is 2 feet and cable speeds may be varied from 2 to 8 feet per second. The cables are electric motor driven through drum pully systems proposed to be installed in the forward end of the cargo bay of the aircraft. The egress cable is illustrated in Figure 4-11.

System Performance:

No test results are available. Performance parameters are based upon calculations and judgements made by Northrop. The following table indicates required jump rates and cable velocities (parachutist walking rate) to achieve a 1000 meter drop zone length (Northrop's goal) without regard to what can actually be achieved in an aircraft when parachutists are burdened and must relatively carefully position themselves in a door prior to jumping.

In order to achieve a 1000 meter long drop zone with 2 sticks of jumpers:

A/C	Aircraft Ground Speed (Knots)	Number of Parachutists	Required Egress Rate (Jumpers/sec/stick)	Required Jumper Walking Rate (ft/Sec)
C-130	120	64	1.98	3.96
C-130	150	64	2.48	4.96
C-141	120	123	3.80	7.60
C-141	200	123	6.36	12.72

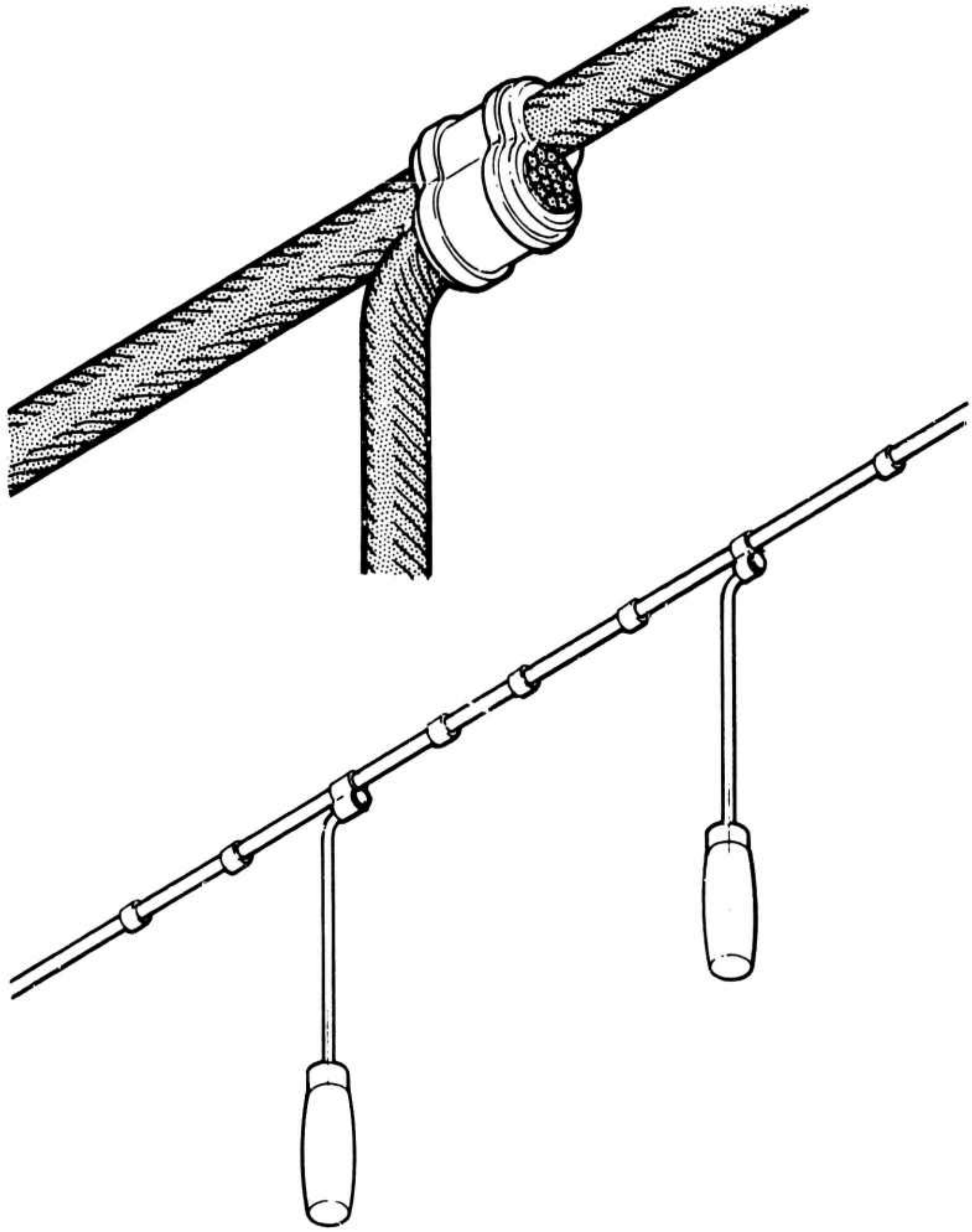


FIGURE 4-11.
EGRESS CABLE

Actual upper limits on egress rate imposed by practical walking speeds and air saturation limit for deploying parachutes were not determined by Northrop. Northrop, however, feels that a walking rate of 8 feet per second is the upper limit for individuals unburdened by either parachute or field pack.

As determined in Section 3.1, a minimum jump interval of 0.4 sec. is required to prevent contact between adjacent jumpers in a stick just outside the aircraft. If jumper spacing inside the aircraft is two feet, a walking rate paced by the egress cable of 5.0 ft/sec produces the smallest allowable jump interval (0.4 sec.). It is not known if fully burdened troopers can move toward jump doors that quickly with the egress cable.

System Installation:

Installation in the C-130 is described as requiring no aircraft modification. C-141 installation is thought by Northrop to be similar to C-130 installation but is not described. The following excerpt from Reference 13 describes installation of the system in C-130 aircraft:

"Installation of the Egress Subsystem in the aircraft will be accomplished by utilizing four standard aircraft litter stanchions. Two stanchions will be located at each end of the troop compartment and these members will form the main supporting structure for the motor driven and idler pulleys. Should additional structural support be necessary, the aircraft floor tie-downs will be used. This method of installation makes it unnecessary to modify the aircraft for adaptation of the Egress Subsystem.

The drive motor will be located at the forward end of the troop compartment (Station 245). This location was selected to take advantage of the cargo winch power receptacle."

Power Requirement:

A separate 8.8 horsepower, 24 volt DC motor is provided to drive each of the two overhead egress cables. Power for the motors is obtained from aircraft winch power receptacles. Variable speed control is provided by rheostats in series with the shunt wound fields of the motors. Motor power requirements depend on resisting force per man and cable speed. At a movement rate of 6 feet per second and 20 men per cable resisting cable motion with 20 lbs. each, 4.4 horsepower are required providing a design factor of 2.0.

Logistical Support Requirement:

No expendable hardware items are required. The cable system with motors may comprise a low weight, low volume package which could probably be stowed in the aircraft during normal transport operations.

Development Cost:

Minimal.

Operational Cost:

Minimal.

4.2.3 Ramp Personnel Conveyor (RPC)

Descriptive Reference:

This Document.

State of Development:

Conceptual.

System Operation:

The Ramp Personnel Conveyor (RPC) concept provides for controlled egress of three parallel sticks of parachutists jumping from the open aft loading ramp of the three types of transport aircraft being considered (Figure 4-12). The system consists of a "moving sidewalk" type of conveyor belt designed as a modular unit to be mounted on the loading ramps of the aircraft. The conveyor is about 10 ft. long and is the full width of the aircraft floor. The primary function of the conveyor is to maintain an even interval between jumpers in a stick and to synchronize the several sticks. It is required to insure non-interference between jumpers during parachute deployment and early stages of their descent while providing minimum safe spacing (or maximum permissible egress rate).

The conveyor allows troopers in three sticks to walk on to the moving belt. They are allowed several seconds to position themselves correctly for jumping from designated standing spots. These spots are marked at intervals along the belt to provide slight longitudinal separation of men in adjacent sticks. The men are carried to the aft edge of the ramp while assuming the "door position" and are caused to exit the aircraft at a rate determined by the belt speed.

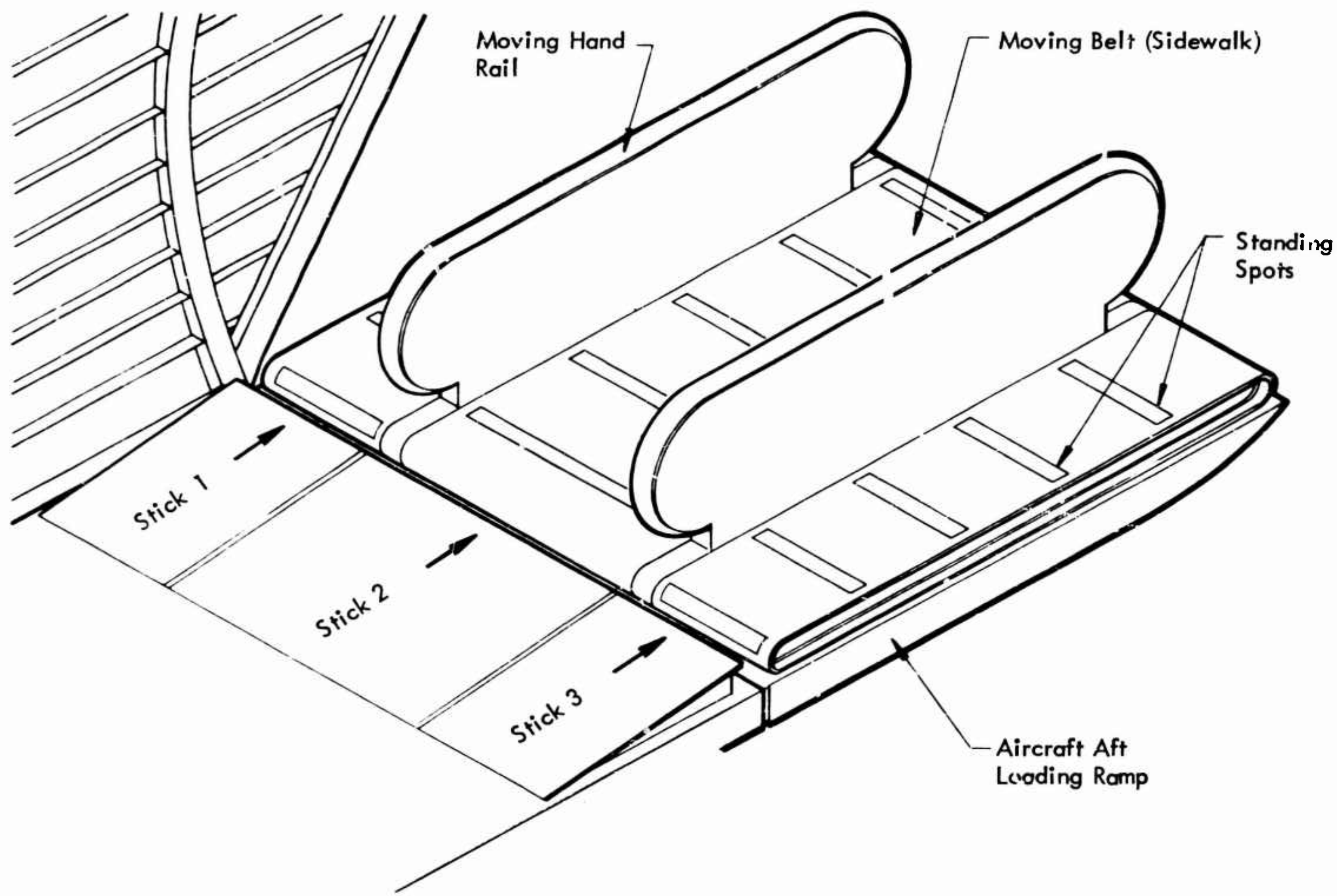


FIGURE 4-12.
RAMP PERSONNEL CONVEYOR INSTALLATION

System Performance:

If a 3 ft. spacing between men in a particular stick is assumed, a 3 ft/sec. speed (a slow walk) provides a total egress rate one and one half that which presently exists with one man per second exiting from each of two side jump doors. Men in adjacent sticks on the belt would be spaced 12 inches apart longitudinally and are caused to jump at intervals of 0.33 seconds. A man is allowed a very adequate 3.3 seconds of time on the moving belt in which to properly position himself to jump.

It is felt that a jump interval of 0.33 seconds is the maximum allowable to prevent interference between troopers outside the aircraft. An egress rate off the ramp this high is probably possible because of the slight lateral separation between sticks of jumpers standing on the ramp. In Figure 3-4 it was shown that a minimum jump interval in a single stick should probably be no less than 0.4 sec. With the slight lateral separation between sticks in the RPC system, a 0.33 sec. jump interval seems reasonable.

This system, additionally, has the advantage that door bags of equipment can be loaded on the conveyor ahead of the first men and dropped as the conveyor is turned on.

System Installation:

The Ramp Personnel Conveyor is envisioned as a modular conveyor system consisting of an endless reinforced rubber belt stretched over rollers which are supported by a frame that contains the variable speed electric motor drive system. The modular conveyor would be designed to fit on the aft loading ramps of the 3 types of aircraft, be easily emplaced and removed, and allow the ramp to be in the closed or open position while the conveyor is installed. The conveyor would be marked so that foot positions would be indicated for each of three lanes (one for each stick). Appropriate lighting would be installed to allow proper foot positioning during night operations. Either fixed or moving hand rails will be provided for each lane as determined to be necessary. Three parallel static line anchor cables will run overhead and be extended out the open aft of the aircraft as necessary to prevent interference of static lines and deployment bags with subsequent jumpers. The anchor line extension will also allow later parachute opening and will be designed to preclude interference of parachutes with portions of the aircraft (presently parachuting from the ramp of the C-141 and C-5A is not permitted because of interference between parts of the aircraft and deploying parachutes).

Power Requirement:

Approximately nine (9) men can stand on the conveyor belt at one time. The total load on the conveyor if each man with his equipment is 250 lbs. is about 2,250 lbs. If an effective friction coefficient for the belt system running on a series of rollers is assumed to be 0.1, the maximum belt tension is 500 lbs. If a maximum belt speed of 4 ft/sec is assumed, the power required to be supplied to the belt in steady state operation is about 2 horsepower. A 5 horsepower motor should be adequate to accelerate and operate the belt at speeds of 4 ft/sec or less.

Logistical Support Requirement:

The conveyor system with anchor line extension assembly would be large enough that it would not be practical to carry it in the aircraft at all times. It would take up approximately 90 ft^2 of floor area on the ramp which is space generally used for cargo tie down. It would also have to be removed for regular cargo handling operations. It would, however, be easily air transportable installed in its operating position or perhaps stacked several high in any other cargo space in a transport aircraft. These conveyor modules would probably be stored at field locations where personnel airdrops originate, and would be easily installed and removed. There are no expendable hardware items associated with this system.

Development Cost:

The cost of designing and developing a compact conveyor module is felt to be small. Probably a fair amount of development effort and flight testing will be required in proving the possibility of jumping several sticks of men from the ramps of some of the aircraft. Development of special hardware such as anchor line extensions and skirts or fairings to provide desirable airflow patterns on and aft of the ramp may be a significant part of a total development effort.

Operational Cost:

No expendable items are used. Maintenance, transportation, storage, and installation and removal costs of the conveyor system will constitute the bulk of operational costs.

4.2.4 Two Stage Personnel Parachute (TSP) (Northrop Descent Subsystem)

Descriptive Reference:

Reference 13.

State of Development:

System has been successfully tested.

System Operation:

The Two Stage Personnel Parachute is a device which, while not an Airdrop Controlled Exit System itself, will allow employment of several ACE concepts which are precluded by use of the T-10 static line deployed parachute.

Operation of the two stage parachute system consists of static line deployment of a 5 ft. diameter pilot parachute which serves to initially stabilize the jumper; and after a short time delay, the pilot parachute is used to deploy the main parachute (Figure 4-13). According to Reference 13:

"The pilot parachute performs three primary functions in the system, i.e., (1) it provides an immediate stabilizing force to the jumper to prevent excessive tumbling, (2) it positions the jumper in a good attitude for main parachute deployment at time delay termination, (3) it provides the drag force required for main parachute deployment, and (4) permanent attachment aids even and uniform main canopy inflation, minimizes opening shock, and retains all components as a unit."

The following additional operational details are provided by Reference 13.

"Upon exiting the aircraft, the static line after 3 ft. of travel actuates two 2.2 second delay pyrotechnic cutters on the pilot parachute hesitation loop (stabilization riser) and initiates pilot parachute deployment. The open pilot parachute stabilizes and decelerates the jumper. When the 2.2 second delay expires, the pilot parachute hesitation bridle is severed and the main parachute deployed. During the pilot parachute stabilization period, the jumper is suspended from a point at the harness back strap intersection. A lazy leg riser bypasses the hesitation loop and provides a positive connection to the main

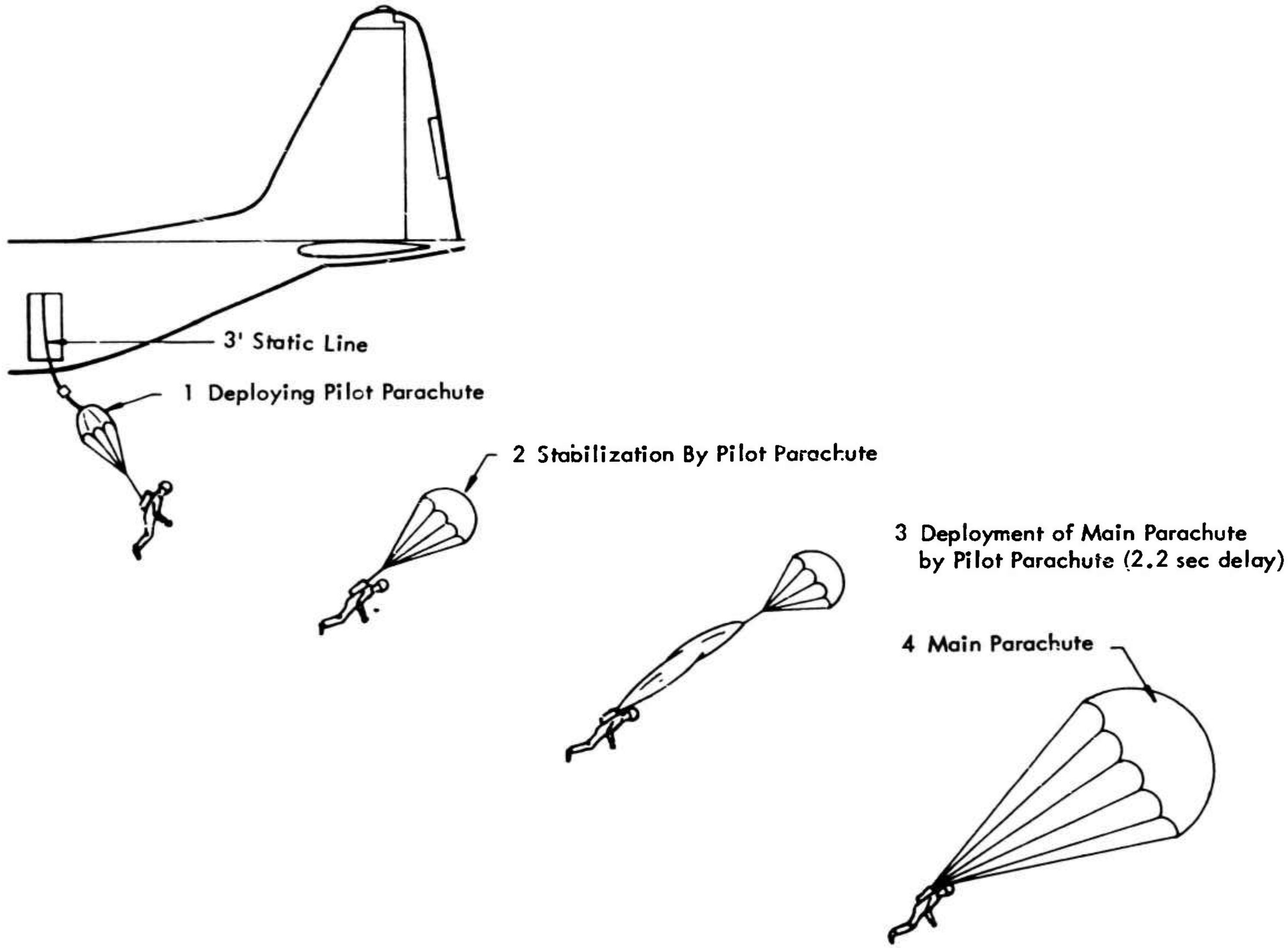


FIGURE 4-13.
TWO STAGE PARACHUTE OPERATION

parachute deployment bag. The main parachute pack flaps are secured by a stow of lazy leg riser through a closing loop to prevent premature pack opening. This system will provide a reliable means for delivering jumpers at airspeeds ranging from 120 to 200 KEAS at an altitude of 500 ft. The system will limit the parachute forces to 2400 lbs. over a nominal operating temperature range of 40°F to 130°F."

Design concepts for the pyrotechnic delay/cutter assembly and stabilization riser rigging are shown in Figures 4-14 and 4-15 respectively.

System Performance:

The two stage parachute system has the following attributes:

1. Aircraft indicated air speeds may be as high as 200 knots while the T-10 parachute is limited to speeds less than 165 to 170 knots.

2. Much less jumper proficiency is required than for the T-10 system. The manner in which the jumper exits the aircraft is unimportant with a two stage system due to stabilization before main parachute deployment which precludes twisting of the deploying main parachute. Egress rate per exit may be increased because it is not necessary for paratroopers to assume correct body positions before jumping. When used in conjunction with a system which aids jumper movement to the door, jump intervals as low as 0.5 seconds are felt to be possible.

3. Long static lines and attached deployment bags are eliminated. These lines limit the exits which may be used and the number of jumpers from certain types of egress points on the transport aircraft being considered.

Reference 13 states that the two stage parachute used in conjuntion with the Northrop Egress Subsystem (Section 4.2.2) would allow two jumpers to exit per second per egress point, a rate which is double that which is achieved with the present T-10 system.

System Installation:

No aircraft modification is required. Present aircraft anchor line installations are adequate for static line deployment of the first stage pilot parachute.

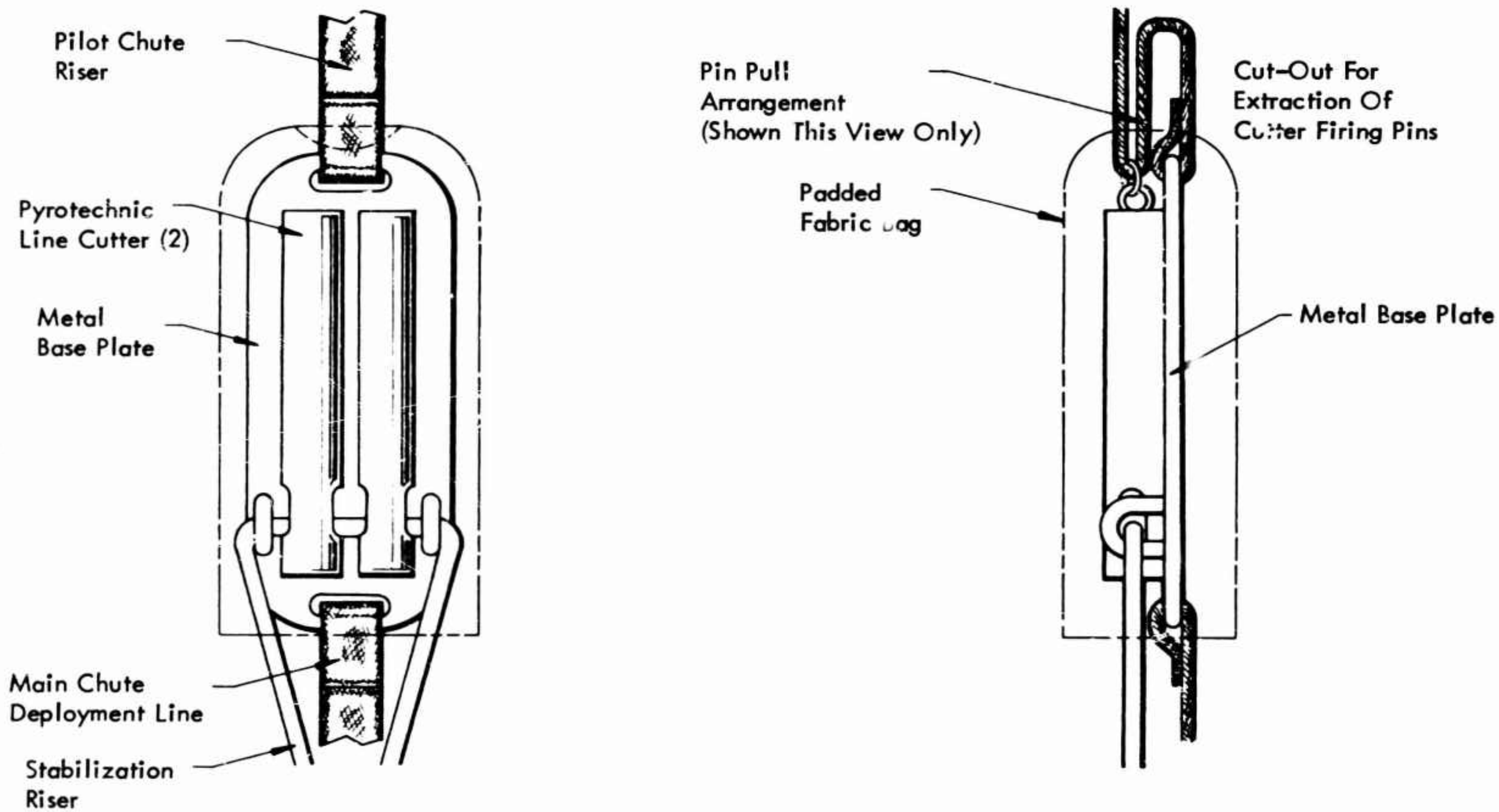


FIGURE 4-14.
CUTTER ASSEMBLY

FIGURE 4-15
CUTTER ASSY & STABILIZATION
RISER RIGGING

Power Requirement:

None.

Logistical Support Requirement:

New pyrotechnic delay/cutter elements must be supplied at the time of parachute repacking.

Development Cost:

Unknown. Some two-stage parachute systems have been successfully tested. Costs to qualify a new personnel parachute system with pyrotechnic actuators could be substantial.

Operational Cost:

Operations costs are probably higher than for the T-10 parachute; however, costs for initial and recurrent proficiency training for jumpers would be reduced.

4.2.5 Ramp and Door Egress I (RADE I)

Descriptive Reference:

This Document.

State of Development:

Conceptual.

System Operation:

Jumpers egress in two sticks from both of the two side jump doors and in two additional sticks off the aft loading ramp of the aircraft. The jumping of four sticks while simultaneously using the aft ramp and jump doors is made possible by employing a two stage personnel parachute (Section 4.2.4) in place of the T-10 system. The time delay between pilot parachute opening and main canopy deployment is set at 2 seconds for the ramp jumpers, and 4 seconds for the door jumpers. The difference in delay to parachute opening allows vertical separation between deploying parachutes of the sticks exiting the doors and from the ramp (Figure 4-16). Vertical separation is the key to allowing high total egress rate while preventing saturation by inflating parachutes.

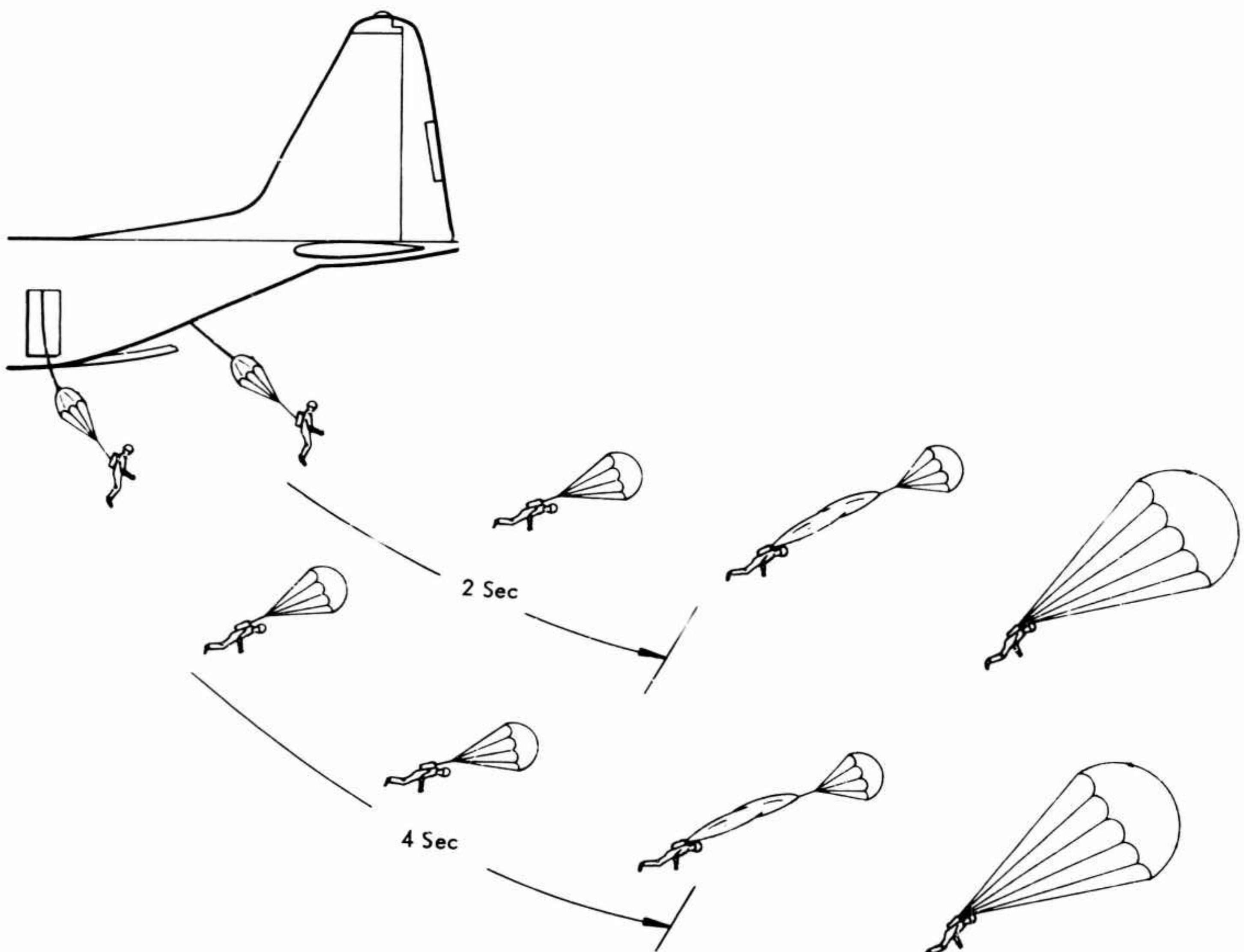


FIGURE 4-16
RADE OPERATION

It is felt that all parachute systems should be of identical design with the capability of either a 2 or 4 second delay being mechanically selected at the time the paratroopers form into sticks in preparation to jump.

The two stage parachute makes possible the use of several egress points not available for the T-10 system:

1. On the C-130 aircraft the use of both the jump doors and aft ramp at the same time for paratroopers is not allowed due to possible interference of closely spaced deploying parachutes. This problem is eliminated if vertical separation is achieved with two stage parachute systems. Additionally on the C-130 when the aft ramp alone is used for jumping, the number of jumpers is limited to 20. This limitation exists because of the hazard to a jumper which exists from a larger number of T-10 static lines and deployment bags which remain attached to the anchor lines and flail around in the aircraft slip stream. A two stage parachute may use a static line as short as 3 feet and no pilot parachute deployment bag.

2. With the T-10 parachute, the side jump doors on the C-141 and C-5A may not be used when the petal doors are open to allow opening the aft ramp exit. This limitation exists because of the possibility of damage to the static line deployed T-10 canopy from contact with the petal doors. A two stage parachute causes the main canopy to be opened well away from the aircraft.

3. While the aft ramps of the C-141 and C-5A are desirable places from which to jump, no mass static line parachuting is allowed due to the hazard of flailing long static lines and deployment bags. Additionally, with these aircraft, the deploying T-10 canopy makes contact with the fuselage and petal doors with the unacceptable possibility of parachute damage. A two stage parachute system, again, causes main parachute deployment away from the aircraft allowing use of the aft ramps for paratrooper egress.

4. Internal airflow in the aircraft due to open side doors and ramp is felt to not be too large a problem. If through flight testing it is determined that internal flow suppressors are desirable, the cabin can be compartmentized with curtains or partitions arranged as shown in Figure 4-17. These comments are also applicable to ACE systems RADE II and RADE III to be described in later sections.

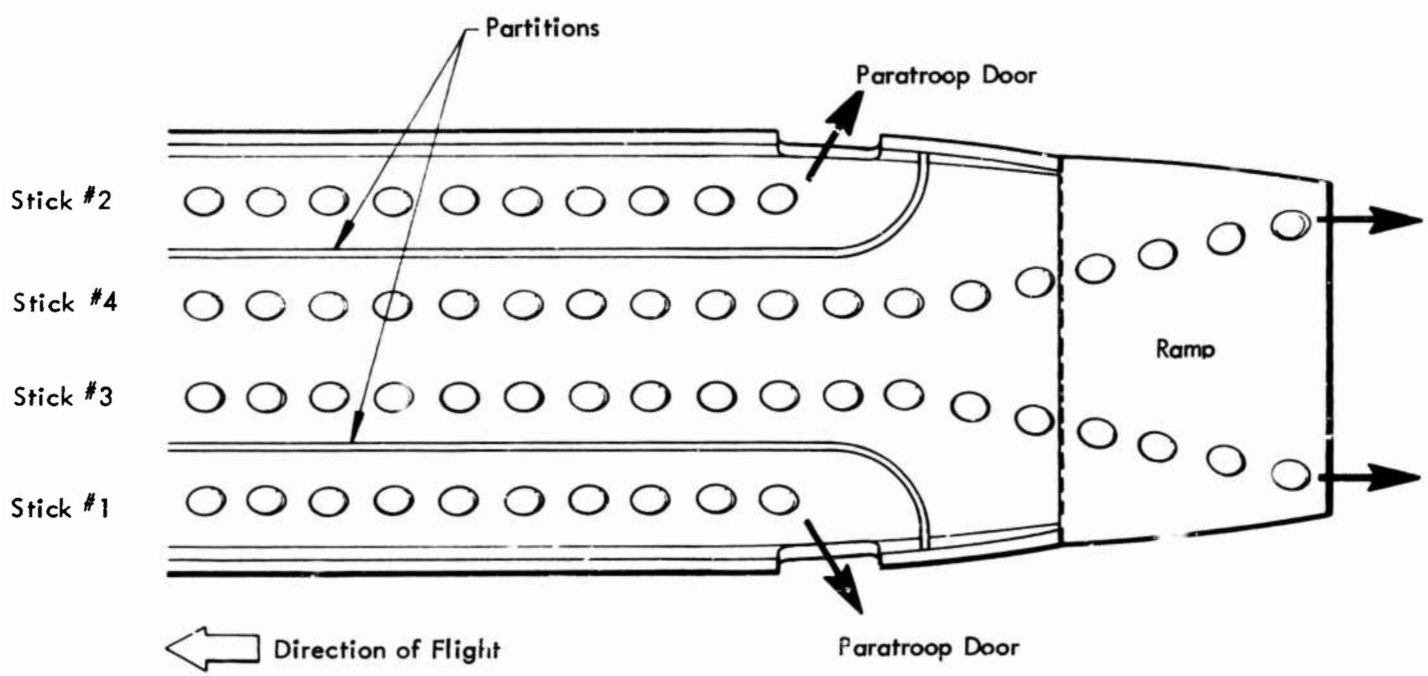


FIGURE 4-17
AIR FLOW PARTITIONS

System Performance:

Four paratrooper egress points become available with the RADE concepts. If the conventional average egress rate of one jumper per second per egress point is maintained, an aircraft is emptied in half the normal time and the length of drop zone is also reduced to half what normally would be required. It may be possible to increase the egress rate in that assuming proper body position prior to jumping becomes less important when a two stage parachute system is used.

System Installation:

Aircraft modification would be limited to installation of internal flow suppressors if required. Anchor lines for door and ramp jumping exist in all aircraft.

Power Requirement:

No aircraft power is required.

Logistical Support Requirement:

No equipment is required in addition to the paratrooper's personal parachute and equipment.

Development Cost:

Minimal after a two stage parachute system is qualified.

Operational Cost:

Slightly more than for T-10 parachute due to higher cost of packing and maintaining two stage parachutes and deployment equipment.

4.2.6 Ramp and Door Egress II (RADE II)

Descriptive Reference:

Reference 14.

State of Development:

Conceptual.

System Operation:

This system allows use of both jump doors and the aft loading ramp for paratroopers jumping with T-10 parachutes from all the aircraft types considered. Extendable booms rigged laterally out from the side jump doors serve two purposes. On the C-141 and C-5A they allow parachutists with T-10 parachutes to jump from the side doors with the aft ramp down and petal doors open. On all the aircraft they provide lateral separation between personnel jumping from the ramp and side doors and prevent interference between deploying parachutes in the several sticks. Two additional extendable booms are rigged longitudinally overhead of the aft ramp. The anchor line extensions provided by the booms cause parachute deployment to be initiated farther aft and will prevent parachute canopy contact with the aft fuselage of the C-141 and C-5A. These anchor line extensions additionally serve in static line management by allowing static lines and attached deployment bags to trail aft of the aircraft where they will not interfere with jumpers.

Figure 4-18 shows the installation of the extendible booms. The side door booms slope downwards so that the side door parachutists may slide laterally outward while attached to the booms. They are held to the boom by a short riser attached to their parachute harnesses and released at the end of the boom. A possible arrangement for holding and releasing the support risers as well as attaching static lines is shown in Figure 4-19. The boom consists of a piece of steel tubing containing the anchor cable and slit to allow the parachutists support riser to pass through while retaining the bulbous end fitting of the riser.

An additional feature of this egress system is the employment of breakaway static lines to remove the clutter and danger to jumpers from flailing static lines. The breakaway static line mechanisms used is the same as used on static lines for extracted platform loads from C-141 aircraft and others and described in the C-141 Loading Manual. The breakaway static line modifications and addition of the support riser would be made to standard T-10 parachutes.

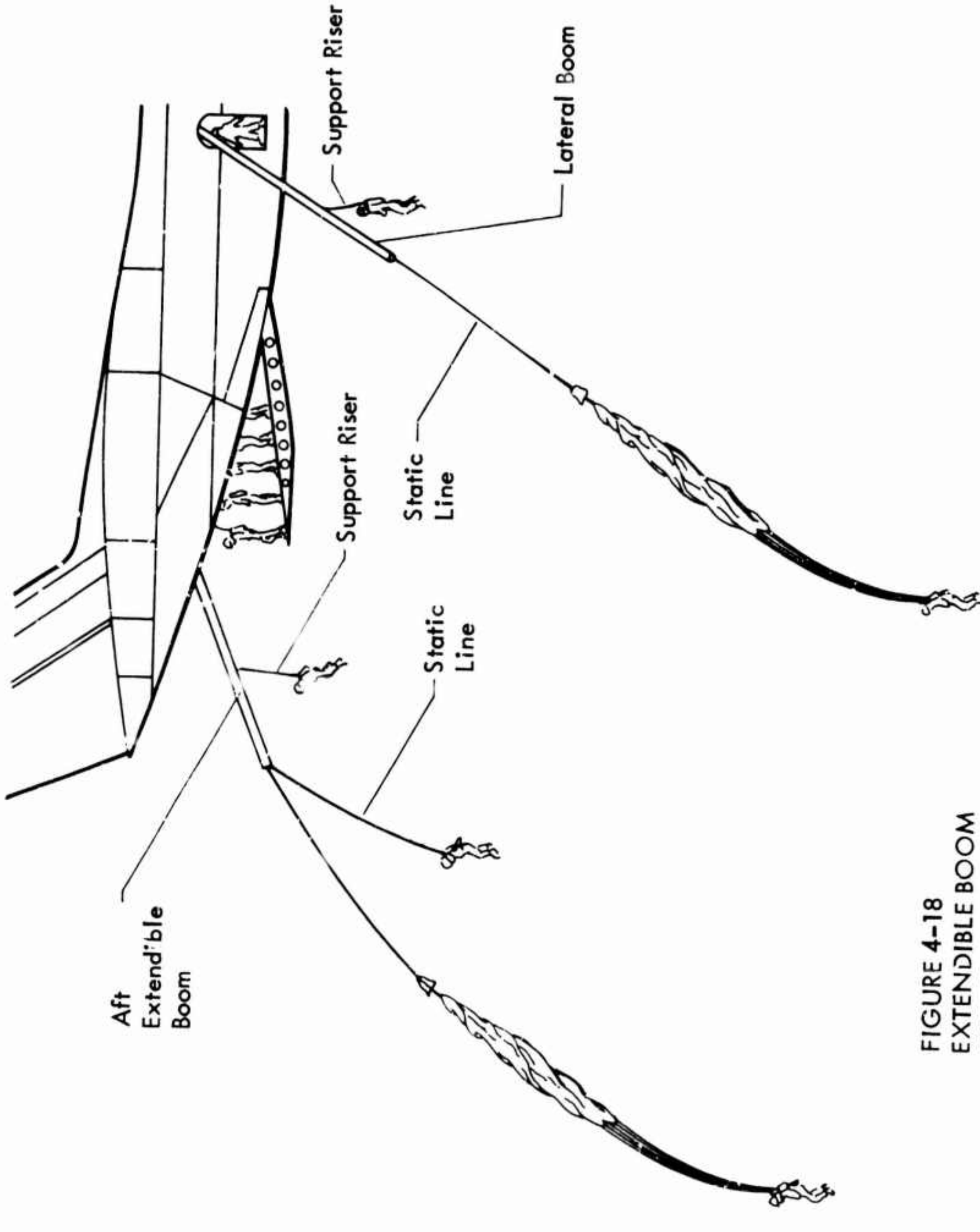


FIGURE 4-18
EXTENDIBLE BOOM
EGRESS SYSTEM

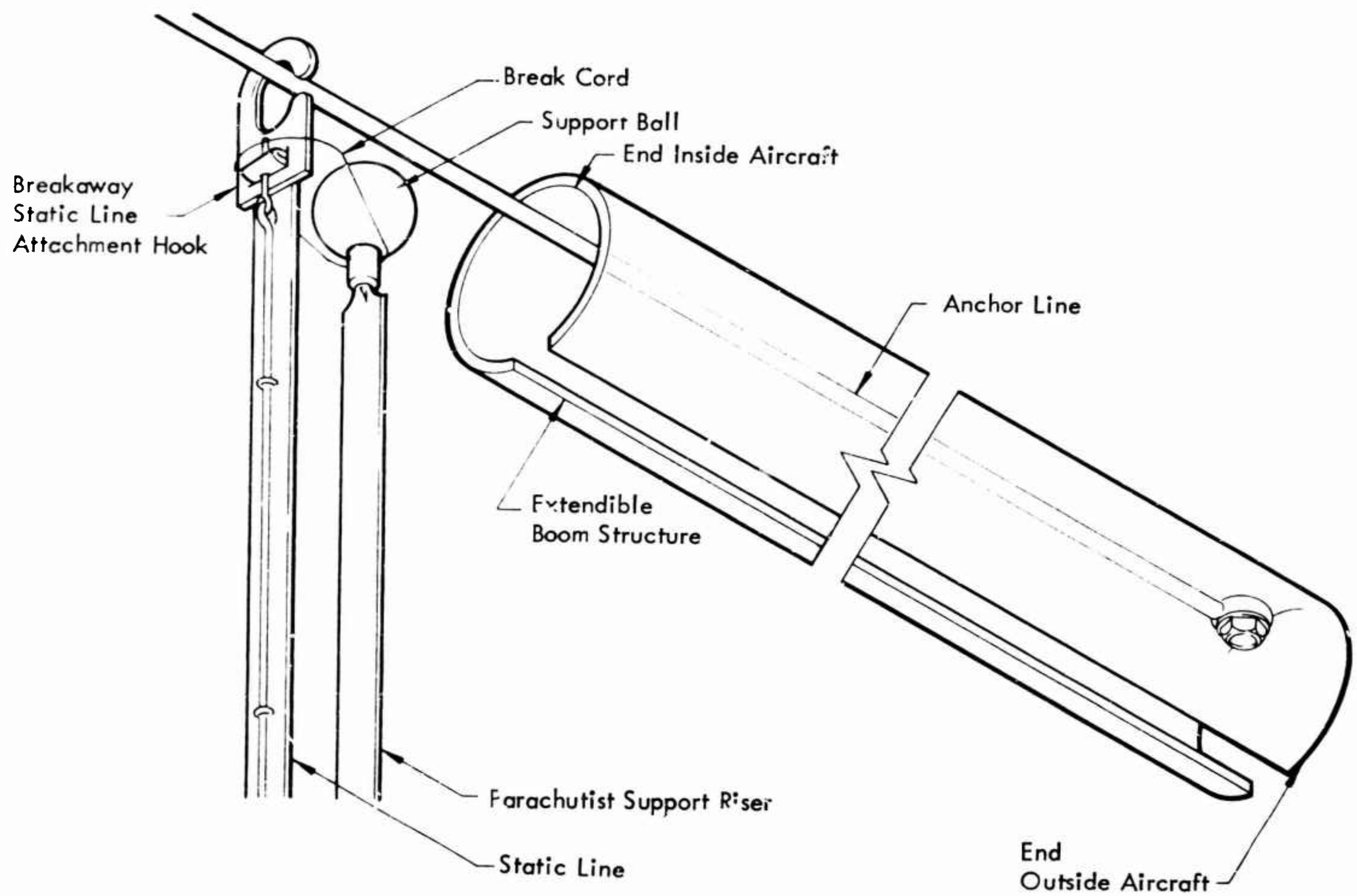


FIGURE 4-19
DETAILS OF EXTENDIBLE BOOM, PARACHUTIST SUPPORT RISER ATTACHMENT, STATIC LINE AND ANCHOR LINE ATTACHMENT

The side jump door booms provide lateral separation of the sticks of door jumpers from the ramp jumpers. With the breakaway static line, the side door booms may possibly be eliminated and vertical separation of the sticks may be used instead of horizontal separation. This change may be accomplished by having the side door jumpers equipped with relatively long static lines (say 50 - 75 ft.). The breakaway feature of the lines precludes the possibility of entanglement of jumpers with trailing static lines while allowing the parachutes of the door jumpers to start deployment well below the aircraft and the parachutes of the ramp jumpers.

Performance:

This system allows the simultaneous deployment of four sticks of parachutists while using the T-10 parachute. Total egress rate should therefore be about twice that presently achieved using only two side jump doors.

System Installation:

This system would require some aircraft modification to provide attachment points and extension hardware for rigging the extendible booms. The booms and associated hardware would be supplied as an airdrop system kit which is readily installed and removed from the aircraft. Mechanical design of the system would be such that the booms would be installed retracted overhead in the cargo compartments of the aircraft and be mechanically extended in-flight near the drop zone. After the airdrop is made, the booms would be retracted again and all jump doors shut to clean up the aircraft for cruise flight.

Power Requirement:

Some electrical power may be required for boom extension and retraction.

Logistical Support Requirement:

The extendible boom airdrop kit would be required to be made available at air bases where personnel airdrop flights originate. Alternately, the kits, if packaged compactly, may be carried in the airdrop aircraft at times when they are operating at least part time for personnel airdrop.

Development Cost:

The following hardware items require development:

1. Side door extendible booms, anchor line attachments and extension mechanism.

2. Ramp overhead extendible booms, anchor line attachments and extension mechanism.

3. Parachutist support riser, support riser end fitting and breakaway static line.

4. Internal flow suppressors if required.

Operational Cost:

Operational costs in excess of the standard T-10 system are associated with the provision and maintenance of the extendible boom airdrop kits.

4.2.7 Extracted Personnel Module (EPM)

Descriptive Reference:

This Document.

State of Development:

Conceptual.

System Operation:

Figure 4-20 illustrates the Extracted Personnel Module Concept. Troopers are carried in a cabin module which is installed in the cargo compartments of the transport aircraft. The module is extracted at the drop zone with the standard cargo extraction parachute technique, and allowed to descend with a system of redundant main parachutes. The module is structurally able to withstand 1 g extraction acceleration, and energy absorbing devices are provided to attenuate the impact which occurs in decelerating from a 20 ft/second descent velocity at ground impact. The module is provided with seating for the soldiers during flight, and emergency escape doors in the module are provided at positions which line up with the paratrooper jump doors in the aircraft. These doors provide egress points in case of an aircraft emergency. An environmental control system can be built into the module.

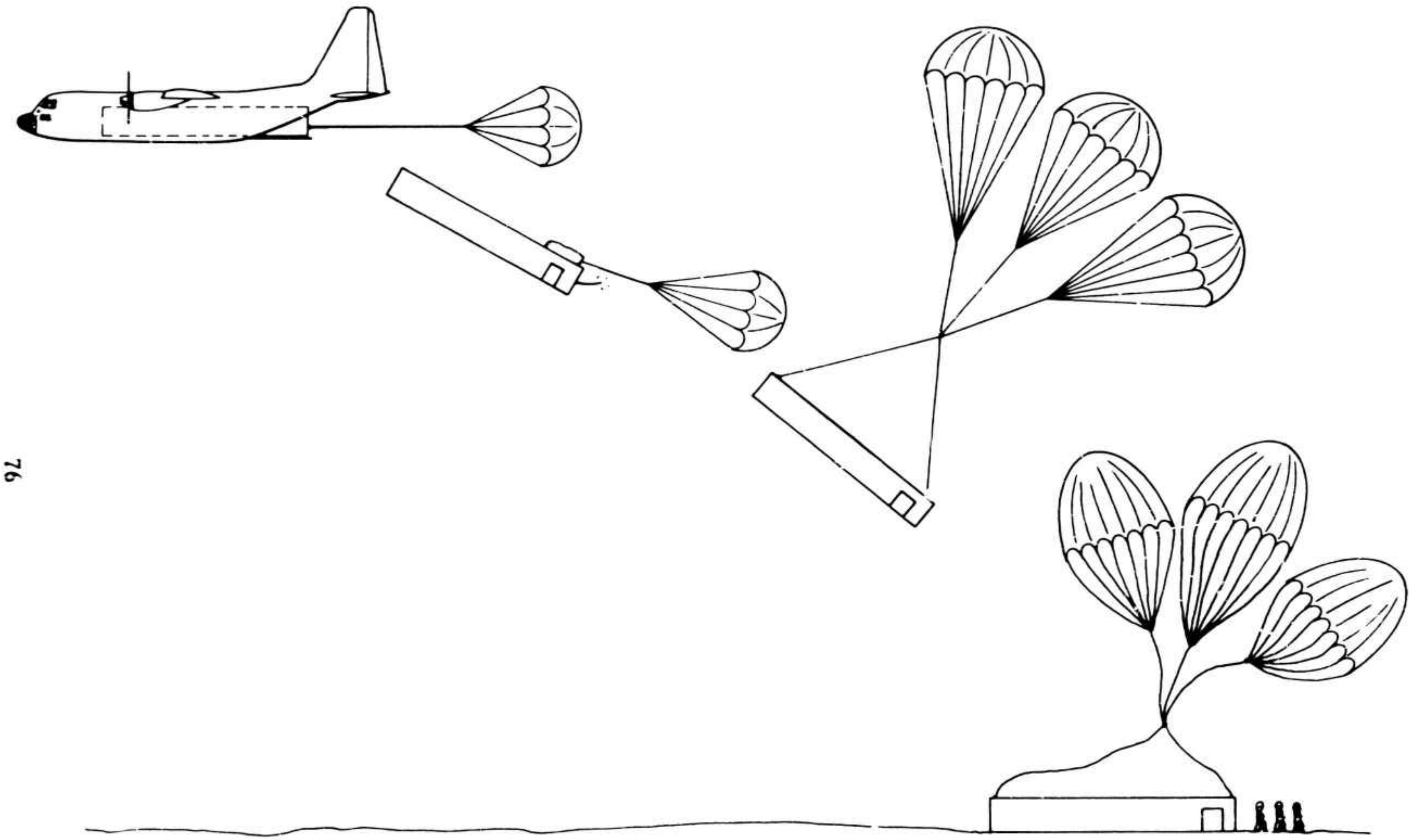


FIGURE 4-20.
EXTRACTED PERSONNEL MODULE CONCEPT

System Performance:

For C-130 and C-141 aircraft, a total aircraft load of paratroopers is landed at one spot on the drop zone with no dispersion due to sequential egress from the aircraft. For the C-5A, several personnel modules may be sequentially extracted. Ground dispersion of the modules would then be similar to that for an equal number of airdropped platform loads. The number of troops carried per aircraft would be reduced somewhat due to the weight and volume of the module itself.

System Installation:

The Extracted Personnel Module rides on the aircraft cargo handling floor rollers and is held in place by the dual rail cargo handling system restraint/release mechanism. The module contains its own descent parachute subsystem and associated extraction and force transfer hardware. Access into the module from the flight deck is provided, and the aircraft environmental control system provides conditioned air to the occupants through openings to the aircraft cargo area.

Power Requirements:

Aircraft power must be provided to the module for lighting and interphone communications.

Logistical Support Requirements:

A personnel module must be provided for each aircraft load of troops dropped. In some circumstances the modules would be recoverable by truck or helicopter.

Development Cost:

The development cost is felt to not be too great. Extracted personnel modules have been built (Reference 15), and the technology for extremely reliable descent parachute systems exists through the several manned space vehicle recovery systems presently operational. Additionally, cabin modules exist for the C-130 (Reference 16). The present modules are, however, not of sufficient structural strength for the EPM system. The cost of proving that the reliability of this type of system is sufficiently great would be large.

Operational Cost:

The operational cost depends much on the recoverability and reuse of the modules. While the cost of using expendable modules seems high, the cost of jump personnel training and equipment would be greatly reduced.

4.2.8 Ramp and Door Egress III (RADE III)

Descriptive Reference:

This Document.

State of Development:

Conceptual.

System Operation:

Both the side jump doors and aft loading ramps may be used for paratrooper jumping if static line length is significantly increased on the T-10 parachute. Longer static lines allow parachutes to deploy farther aft of the aircraft for ramp jumpers and prevent parachute contact with the aft fuselage. Static line lengths for ramp jumpers could be increased from 15 feet to about 40 feet.

Increasing static line length to about 100 feet would accomplish two things for door jumpers. Parachute deployment would occur well below the aircraft preventing interference between deploying parachutes and the petal doors on the C-141 and C-5A. The second vital function of the longer side door static lines is to provide vertical separation between the deploying parachutes of the sticks jumping from the ramp and doors. Operation of the concept is shown in Figure 4-21.

The key to being able to use long static lines to initiate parachute opening farther away from the aircraft lies in the use of breakaway static lines. The breakaway static line is presently used to "clean up" the cargo bay of aircraft dropping sequential platform loads. These breakaway static lines are used on the static line actuated knives which are part of the extraction parachute force transfer mechanism. The breakaway static line installation is described in Reference 17 and illustrated in Figure 4-22.

Performance:

Four jumper egress points are made available on each aircraft allowing the total egress rate to be doubled. The drop zone length is then approximately half that required for the standard T-10 system.

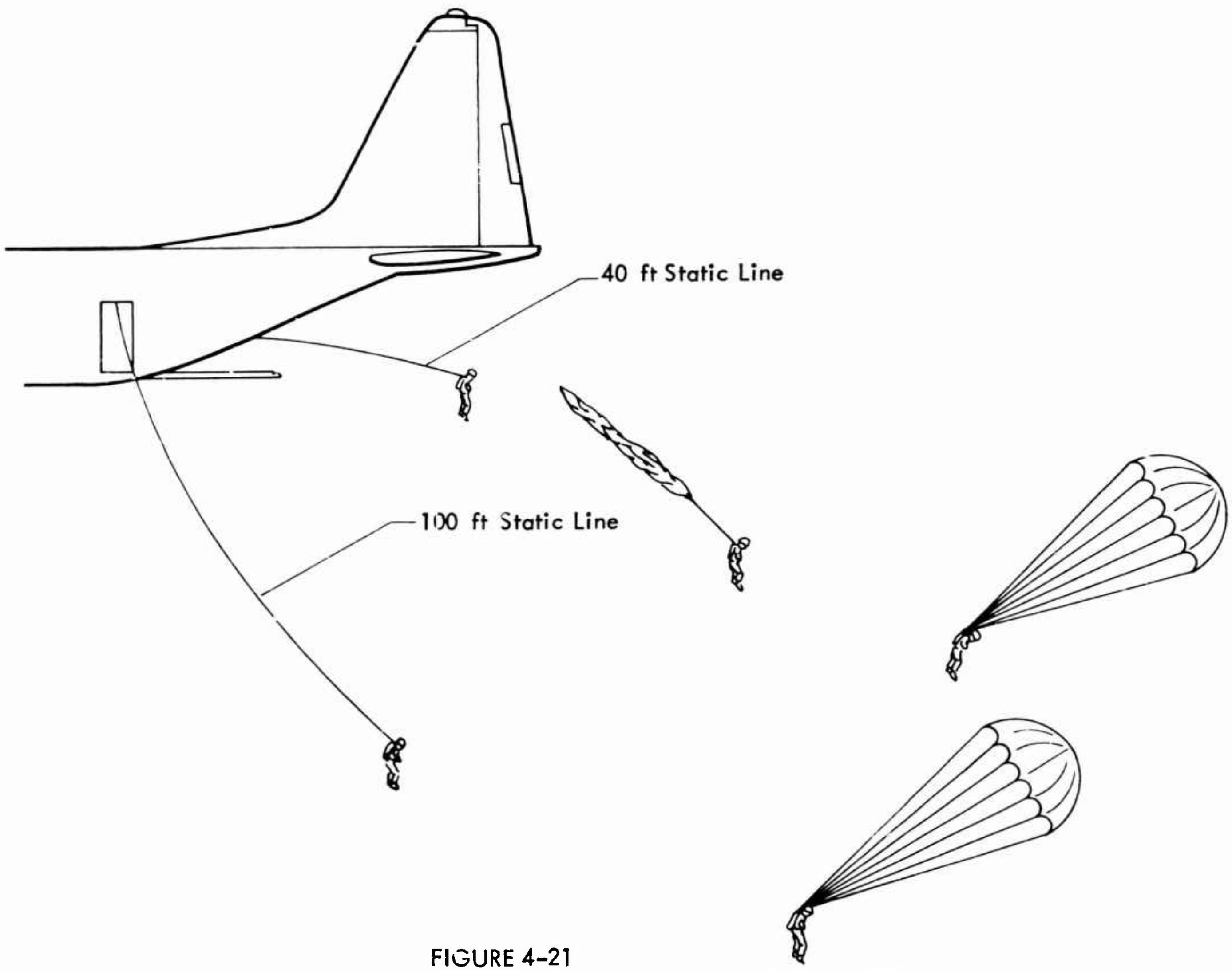


FIGURE 4-21
LONG STATIC LINE CONCEPT OPERATION

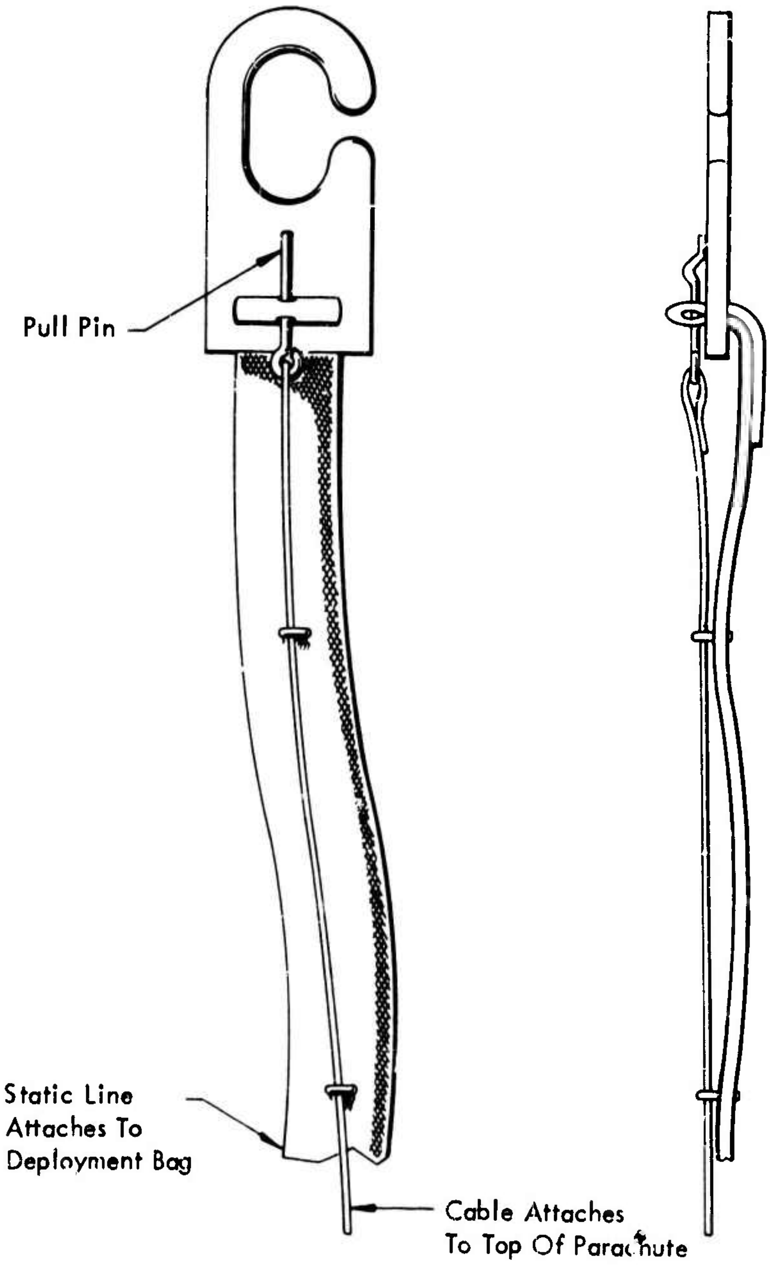


FIGURE 4-22
BREAK AWAY STATIC LINE

System Installation:

No aircraft modification is required unless internal flow suppressing wind screens are found to be necessary.

Power Requirement:

No aircraft power is required.

Logistical Support Requirement:

No equipment other than the jumper's personal equipment is required.

Development Cost:

The development cost is felt to be small. A significant amount of testing of the long breakaway static lines with drop test of dummies will be required. It must be shown that the longer static lines do allow excessive tumbling of the jumpers with T-10 parachutes. Additionally, the breakaway feature of the static lines must be proven.

Operational Cost:

Operational cost should be more than for the current T-10 system for two reasons. 1. The deployment bags and static lines are lost and not reusable. 2. Training costs should be higher due to the importance of maintaining proper body position.

5.0 ACE SYSTEM EVALUATION SCHEME

This section describes a Figure-of-Merit Scheme to be used in comparatively evaluating the several ACE System Conept previously described. For each type of ACE System (Personnel and Platform Loads) a Standard for Comparison is established. A point system which compares performance of ACE Systems in several areas of interest to the performance of the chosen Standard Systems in those areas is then used. Point totals for all systems then show their relative rank in the evaluation. The ACE Systems chosen as Standards have a point total of 0. All other systems may have point totals ranging between -100 and +100.

The specific system attributes or characteristics which are considered in the evaluation scheme with their individual range of point totals are:

Points			System Evaluation Characteristic
Max.	Standard System	Min.	
20	0	0	Drop Zone Dispersion Reduction
0	0	-20	Aircraft Airdrop Payload Capability Reduction Due to ACE System Installation
20	0	-20	Operational Flexibility and Field Acceptance of ACE System
20	0	-20	Operational Cost
10	0	-10	Safety and Reliability of ACE Airdrop Operations
10	0	-10	Development Cost
10	0	-10	Aircraft Modification and Initial ACE System Installation Cost
10	0	-10	ACE System Transportability and Logistical Support Requirement
100	0	-100	

The ACE concepts chosen as standards of comparison (zero point totals) are:

(1) For platform loads, the Standard Airdrop System (SADS) described in Section 4.1.1 which employs sequential parachute extraction of loads at 4 - 5 second intervals.

(2) For personnel airdrop, parachutists using the T-10 parachute jumping at one second intervals from two side jump doors.

The point system adopted in the evaluation scheme is designed to show systems which have the most potential for further consideration. No systems are considered which require longer drop zone lengths than the systems chosen as standards. Therefore, up to 20 points may be gained by systems for drop zone length reduction which is the prime system characteristic to be studied in the program. Aircraft payload capability reduction due to an ACE System installation may cost a system up to 20 points in the evaluation scheme. The systems which are standards are assumed to allow the maximum aircraft payload capability, and other systems can only have equal or less capability in this area. Operational flexibility and operational cost are system characteristics which can individually contribute or reduce point totals by 20 points. Other system characteristics which are used in the evaluation can individually add or take away 10 points.

The point system is such that a simple reduction in drop zone length will be offset by attendant large reductions in flexibility, payload capability, or increased operational cost. For example, an ACE system which will allow the spot landing of a total aircraft load, but which grossly reduces the amount of payload carried will gain 20 points for Drop Zone Length Reduction, but will lose close to 20 points for Aircraft Payload Capability Reduction. It will additionally lose up to 20 points for its loss of operational flexibility and will lose more points for its Increased Operational Cost. The system will therefore have a point total well below that of the Standard System. To score well, ACE Systems must therefore reduce the drop zone length while performing well in other areas.

5.1 Performance of Standard Systems

The following describes the assumed performance of the selected standard systems for both platform loads and personnel airdrop.

5.1.1 Platform Load Standard System

If the effects of winds are neglected, the drop zone length required by an ACE system utilizing sequential expulsion or extraction of platform loads is determined by the number of platforms in the stick, the period of the extraction cycle, and the true airspeed of the aircraft. For purposes of comparing ACE concepts, the standard for comparison will be the Standard Airdrop System used in conjunction with the C-130E aircraft. The aircraft is assumed to be delivering four sequential 8,000 lb. platform loads. An aircraft true airspeed of 130 knots and a constant extraction cycle period of 4.5 seconds are assumed. In no wind conditions the ground distance between the first and last load is 3,000 feet (the distance between adjacent loads on the ground is 1,000 ft.).

5.1.2 Personnel Airdrop Standard System

The standard for comparison for ACE personnel drop systems will be the C-130 aircraft dropping 64 total parachutists with parachutists leaving each of two side jump doors at 1.0 second intervals at each door. In no wind conditions at an aircraft true airspeed of 130 knots, the ground distance from the first to last man out is 7,000 feet. The 1.0 second jump interval per egress point is typical of the jump interval achieved by normally burdened parachutists using the Standard static line deployed T-10 parachute.

5.2 Platform Load System Evaluation Characteristics

The following sections describe the methods used for point assignments for the eight System Evaluation Characteristics as applied to ACE Concepts for platform load delivery.

5.2.1 Drop Zone Dispersion Reduction

The ground distance between platform loads delivered by the Standard System is 1,000 feet. The total drop zone length for four loads is 3,000 feet. A system which achieves a 3,000 ft. drop zone length is allowed 0 points. A system which achieves a zero length drop zone (single point) is allowed 20 points. Systems which require more than 3,000 ft. are not considered. Systems are therefore allowed 0.0067 points per ft. reduction in drop zone length below 3,000 ft. as illustrated in the table below:

Drop Zone Length (ft.)	Points Allowed
3,000	0
2,500	3.33
2,000	6.67
1,500	10
1,000	13.33
500	16.67
0	20

5.2.2 Aircraft Airdrop Payload Capability Reduction Due to ACE System Installation

The Standard Airdrop System for platform loads is felt to minimally restrict aircraft payload weight and volume carrying capability. Other ACE Systems may allow equal or less aircraft airdrop payload. The following table shows points allowed for various degrees of payload reduction for the C-130E aircraft.

Percent of Maximum Payload	Points Allowed
100	0
87.5	-5
75	-10
62.5	-15
50	-20

It can be seen that the point system is such that with all other system characteristics equal, a 50% reduction in drop zone length accomplished with an attendant 50% decrease in aircraft payload has a detrimental effect on the point total for the system.

5.2.3 Operational Flexibility and Field Acceptance of ACE Concept

Field commanders need to have the capability to decide the makeup of an airdrop load according to changing field requirements.

Airdrop loads which require long lead times to prepare for airdrop are less desirable than loads which may be quickly prepared and arranged according to changing battle field conditions.

The Standard Airdrop System for platform loads is designed to handle airdrop loads rigged on either Combat-Expendable or Reusable Cargo Platforms in accordance with the instructions of Reference 18. Rigged airdrop loads according to Reference 18 generally consist of one piece of equipment and associated hardware rigged on platforms 8 to 20 feet long. Extensive procedures are specified for installation of tie downs, impact absorbing materials, and connection of extraction and descent parachutes. While extensive preparation of a load is required, the individual pieces of equipment may be prepared for airdrop well in advance. An aircraft airdrop payload may then be made up on short notice when it is determined what individual equipment items are required at the drop zone.

An ACE System which uses standard rigged loads as specified in Reference 18 is allowed zero points.

System which allow less flexibility because more lead time is required in preparing a total aircraft load for airdrop loses points. Systems which require less last minute preparation in loading the aircraft gain points. The range of points awarded for operational flexibility is -20 to 20. Examples of systems which are awarded the maximum and minimum points are given below:

Extremes of Operational Flexibility	Points Awarded
Total aircraft payload rigged in conventional manner after equipment requirements are determined by field commander.	-20
Platform loads rigged in accordance with TM 10-500-16 and stored. Pre-rigged loads loaded in aircraft after equipment requirements are determined by field commander.	0
Total aircraft payload selected from storage and loaded in aircraft with ACE System which required no cargo tie down or other preparation for airdrop (e. g., equipment loaded in a large bin packed with crushable material and airdropped as a unit.	20

5.2.4 Operational Cost

Operational cost comparisons are made on the basis of cost per unit weight of delivered hardware. Operational costs include the cost of load preparation, the cost of flight operations and the cost of all airdrop hardware, which for the purposes of this study, are considered to be non-recoverable/reusable. Airdrop hardware includes rigging materials, load platforms, extraction and descent parachute subsystems and all other hardware which leaves the aircraft during the drop operation. The following table shows point allowances for various operating costs. The Standard System is awarded zero points.

Percentage of Standard System Operational Cost	Points Awarded
12.5	20
25	15
50	10
75	5
100	0
125	-5
150	-10
175	-15
200	-20

5.2.5 Safety and Reliability of ACE Airdrop Operations

It is assumed in this study that inherent safety and reliability of an ACE System may at least in part be quantified in terms of system complexity. The following table shows points awarded for various degrees of system complexity. Again, the Standard System is the basis for comparison and is awarded zero points.

Percentage of Standard System Complexity	Points Awarded
12.5	10.0
25	7.5
50	5.0

75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.2.6 Development Cost

Development cost is related to system complexity and current state of development. Less development risk and cost would be expected from systems which have been conceptually demonstrated or used in some other form. Points awarded in the area of development cost, however, are based upon technical feasibility of a system. Technical feasibility may be judged by analytical predictions or actual flight test of ACE Concepts.

The following table shows points awarded for various degrees of technical feasibility. The Standard System is awarded zero points. In this evaluation it is assumed that the Standard System is only a concept. Other systems which are judged to be technically less expensive to develop are awarded positive points while systems which are judged to have a higher development cost than the Standard System (if the Standard System were now being developed from a concept) are awarded negative points.

Percentage of Standard System Assumed Development Cost	Points Awarded
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.2.7 Aircraft Modification and Initial ACE System Installation Cost

It is assumed that all ACE platform load concepts are generally compatible with the Dual Rail Cargo Handling Systems presently installed in the C-130, C-141 and C-5A aircraft. The cost of changes to the Dual Rail System, the aircraft itself, or the cost of additional equipment for extraction or expulsion of the aircraft payload are considered in this section. Aircraft modification and system installation costs are compared to the assumed cost of installation of the Airdrop System components associated with the extraction parachute holding and pendulum release equipment of the Standard Airdrop Systems. Installation is assumed to be in the C-130 type aircraft.

The following table shows point allowances for various Installation costs compared to the assumed installation cost of the extraction parachute deployment hardware of the Standard Airdrop System.

Percentage of Standard Airdrop System Installation Cost	Points Allowed
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.2.8 ACE System Transportability and Logistical Support Requirement

ACE System equipment must be available at the site at which aircraft are prepared and loaded for an airdrop operation. ACE System equipment is taken to include all hardware for preparing airdrop platform loads and all hardware associated with the extraction and descent systems employed. Components of the Dual Rail Cargo restraint system are not included.

Complexity of logistical support requirements of various systems are compared to that of the Standard System. The following table shows points awarded for various complexities of support requirements.

Percentage of Standard Airdrop System Logistical Support Complexity	Points Allowed
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.3 Personnel Airdrop System Evaluation Characteristics

The following sections describe the methods used for point assignments for the eight System Evaluation Characteristics as applied to ACE Concepts for personnel airdrop.

5.3.1 Drop Zone Dispersion Reduction

The Standard Personnel Airdrop System for the C-130 aircraft drops 64 parachutists using two aft fuselage jump doors with a jump interval of 1.0 second at each door. At a true airspeed of 130 knots in a no wind condition the ground distance between the first and last jumper is 7,000 ft. An ACE System which achieves a 7,000 ft. drop zone length is allowed zero points. A system which reduces the drop zone length to a point (zero length) is allowed 20 points. The following table shows the points awarded for drop zone length. For each foot reduction in drop zone length 0.00286 points are allowed.

Drop Zone Length (ft.)	Points Allowed
7,000	0
6,000	2.86
5,000	5.72
4,000	8.58
3,000	11.44
2,000	14.30
1,000	17.16
0	20

5.3.2 Aircraft Airdrop Payload Capability Reduction Due to ACE System Installation

Sixty-four parachutists carried by the C-130 is taken to be the maximum number that it is possible to carry. Zero points are allowed for ACE Systems which carry 64 jumpers. Negative points are awarded for systems which allow fewer than the maximum number to be carried as illustrated in the table below.

Percent of Maximum Number of Jumpers	Points Allowed
100	0
87.5	-5
75	-10
62.5	-15
50	-20

5.3.3 Operational Flexibility and Field Acceptance of ACE Concept

Airdrop generally does not play a major role in the overall air-transport mission. Airdrop systems should be largely self-contained and require minimum effort to prepare for an airdrop mission. ACE Systems which are largely built into an aircraft with no sacrifice of the aircraft normal capability in air-transport are more desirable than would be ACE Systems which require installation near the time an airdrop is to be made. Small size, easily transportable airdrop system kits would be more desirable than very large elaborate ACE Systems which in themselves require special effort to locate in the field for use.

For an advanced airdrop system to be useful, the airdrop system concept must be accepted. As an example, the use of a descent parachute system per jumper seems more acceptable to airborne type troops than the clustering of several jumpers on a single descent system.

Zero points are awarded for the Standard Personnel Drop System. The range of points available for assignment to other systems is -20 to 20. The number of points awarded a system in this area of consideration is largely subjective. Operational field commanders will probably express views of a system which are different than those of engineering and development personnel. It is desired that points assigned in the area of operational flexibility and field acceptance are done so with both views of a system in mind.

5.3.4 Operational Cost

Operational cost comparisons will be made on the basis of cost per fully equipped parachutists delivered. Operational cost includes the cost of aircraft preparation for the mission, (that is, the re-occurring installation of ACE System hardware). It also includes the cost of all descent system hardware which is assumed non-recoverable, and the cost of the flight operation itself which reflects loss or gain in aircraft payload capability. The table below shows point allowances for various operational costs. Costs are compared to the assumed cost of the delivery of individual parachutists for the Standard (T-10 parachute) System.

Percentage of Standard System Operational Cost	Points Awarded
12.5	20
25	15
50	10
75	5
100	0
125	-5
150	-10
175	-15
200	-20

5.3.5 Safety and Reliability of ACE Airdrop Operations

For personnel airdrop, it is also assumed in the study that inherent safety and reliability of an ACE System is related to system complexity. Simple systems appear more desirable than more complex systems. The following table shows point allowances for various degrees of system complexity as related to the complexity of the Standard Airdrop System.

Percentage of Standard System Complexity	Points Awarded
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.3.6 Development Cost

Development cost is evaluated for personnel airdrop systems in the same way it is evaluated for platform load ACE Systems (see Section 5.2.6). That is, the Standard System is assumed to be only a concept. The development cost of the Standard System from a concept is then the baseline for development cost comparison for other ACE Systems as shown in the table below.

Percentage of Standard System Assumed Development Cost	Points Awarded
12.5	10
25	7.5
50	5.0

75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.3.7 Aircraft Modification and Initial ACE System Installation Cost

Aircraft modification and installation costs are compared to the assumed cost of installation of components for the Standard Personnel Airdrop System in the C-130 type aircraft. These components include anchor line installation, intercomm and light signal components and paratrooper stowable seating arrangements. The following table gives the point allowances for various aircraft modification and installation costs.

Percentage of Standard System Installation Cost	Points Awarded
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

5.3.8 ACE System Transportability and Logistical Support Requirement

Personnel ACE System equipment must either be capable of being carried in the aircraft during other than airdrop operations, or must be provided at a site convenient to the site at which airborne troops are boarded. Complexity of logistical support of various systems are compared to that of the Standard System. Systems which can be contained in the aircraft at all times without sacrificing aircraft mission flexibility and payload are more desirable than systems which require large, cumbersome pieces of equipment which require special transportation to the site of aircraft preparation. The following table shows points awarded for various complexities of support requirements.

Percentage of Standard Airdrop System Support Complexity	Points Allowed
12.5	10
25	7.5
50	5.0
75	2.5
100	0
125	-2.5
150	-5.0
175	-7.5
200	-10.0

6.0 ACE SYSTEMS COMPARISON

The ACE System Evaluation Scheme described in Section 5.0 has been applied to the several ACE concepts defined in the ACE program. For each ACE concept, point assignments have been made for each of the eight System Evaluation Characteristics. Evaluation point totals were then obtained for each concept. The concepts were listed in order of decreasing point totals, thus establishing the relative standings of the individual systems in the comparative evaluation.

Table 6-1 shows the point assignments for each of the eight System Evaluation Characteristics for both the Platform Load ACE Systems and the ACE Personnel Airdrop Systems.

Table 6-2 shows the relative standings in the evaluation of both the Platform Load and Personnel ACE Systems.

PLATFORM LOAD SYSTEMS		1 Drop Zone Dispersion Reduction	2 Aircraft Airdrop Payload Capability Reduction	3 Operational Flexibility And Field Acceptance	4 Operational Cost	5 Safety and Reliability	6 Development Cost	7 Aircraft Modification And Installation Cost	8 Transportability and Logistical Support Reqd	TOTAL
SADS		0	0	0	0	0	0	0	0	0
ISADS 1	(1)	13.3	-0.5	-6.7	0	3.0	0	0	0	9.1
ISADS 2	(1)	14.6	-1.0	-7.5	-1.0	3.0	0	0	-0.5	7.6
ISADS 3	(1)	14.6	-0.5	-6.7	0	3.0	0	0	-0.5	9.9
ISADS 4	(1)	14.1	-0.5	-6.7	-1.5	2.0	-2.5	0	-0.5	4.4
ISADS 5	(1)	15.0	-1.0	-7.5	-1.0	3.0	0	0	-1.0	7.5
ISADS 6	(1)	15.3	-1.0	-7.5	-2.5	2.0	-2.5	0	-1.0	2.8
ISADS 7	(1)	15.3	-0.5	-6.7	-1.5	2.0	-2.5	0	-1.0	5.1
ISADS 8	(1)	15.7	-1.0	-7.5	-2.5	2.0	-2.5	0	-1.5	2.7
ISADS 9		3.6	-0.5	-0.8	-1.0	0	0	0	-0.5	0.8
ISADS 10		4.9	-0.5	-0.8	-1.0	0	0	0	-1.0	1.6
ISADS 11		6.0	-0.5	-0.8	-2.5	-1.0	-2.5	0	-1.0	-2.3
ISADS 12		7.1	-0.5	-0.8	-2.5	-1.0	-2.5	0	-1.5	-1.7
ISADS 13		3.6	0	0	0	0	0	0	-0.5	3.1
ISADS 14		6.0	0	0	-1.5	-1.0	-2.5	0	-1.0	0
ISADS 15		2.2	0	0	-1.5	-1.0	-2.5	0	-0.5	-3.3
MEPS		8.0	0	-5.0	2.5	3.0	-1.0	0	1.0	8.5
RES		20.0	-1.5	-3.0	-3.0	2.0	-2.5	0	-1.0	11.0
EXPOR		4.7	0	0	0	-1.0	-0.5	0	0	3.2
VRTC		2.0	0	-0.5	-0.5	0	0	0	-1.0	0
EES		11.2	-5.0	0	0	-2.5	-10.0	-10.0	-2.5	-18.8
PERSONNEL AIRDROP SYSTEMS										
SPADS	(3)	0	0	0	0	0	0	0	0	0
NES	(4)	6.0	0	-4.0	-2.0	2.0	-1.0	-2.0	-2.0	-3.0
RPC	(5)	6.5	0	-5.0	-2.0	1.0	-1.0	-0.5	-2.5	-3.5
TSP	(6)	6.0	0	6.0	-2.0	0	0	0	-1.0	9.0
RADE I	(7)	13.0	0	4.0	-3.0	0	-1.0	0	-1.0	12.0
RADE II	(8)	10.0	0	-8.0	-2.0	-5.0	-2.5	-5.0	-2.5	-15.0
EPM		20.0	-10.0	-15.0	-20.0	0	0	4.0	-10.0	-31.0
RADE III		10.0	0	-8.0	-2.0	-7.0	-1.0	0	-1.0	-9.0

(1) Assumes Aircraft Tatal Paylaad Consolidated Inta Twa Platform Loads Far Air Drop.
(2) Extroction Cycle Period of 2.0 Sec Assumed Passible.
(3) 2 Egress Paints, 1.0 sec Jump Intervol At Each Exit.
(4) 2 Egress Paints, 0.7 sec Jump Interval At Each Exit.
(5) 1 Egress Point (Aft Ramp) With 0.33 sec Jump Interval.
(6) 2 Egress Points, 0.7 sec Jump Interval At Each Exit.
(7) 4 Egress Paints, 0.7 sec Jump Interval At Each Exit.
(8) 4 Egress Points, 1.0 sec Jump Interval At Each Exit.
(9) 4 Egress Paints, 1.0 sec Jump Intervol At Each Exit.

TABLE 6-1.
ACE CONCEPT COMPARISON

Relative Position	Concept Title	Points
Platform Load Systems		
1	RES	11.0
2	ISADS 3	9.9
3	ISADS 1	9.1
4	MEPS	8.5
5	ISADS 2	7.6
6	ISADS 5	7.5
7	ISADS 7	5.1
8	ISADS 4	4.4
9	EXPOR	3.2
10	ISADS 13	3.1
11	ISADS 6	2.8
12	ISADS 8	2.7
13	ISADS 10	1.6
14	ISADS 9	0.8
15	SADS	0.0
16	ISADS 14	0.0
17	VRTC	0.0
18	ISADS 12	-1.7
19	ISADS II	-2.3
20	ISADS 15	-3.3
21	EES	-18.8
Personnel Airdrop Systems		
1	RADE	12.0
2	TSP	9.0
3	SPADS	0.0
4	NES	-3.0
5	RPC	-3.5
6	RADE III	-9.0
7	RADE II	-15.0
8	EPM	-31.0

TABLE 6-2.
ACE SYSTEM CONCEPT RELATIVE STANDINGS

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 ACE Systems for Platform Loads

The Rapid Extraction System (RES) received the highest numerical score in the evaluation. In concept such a system is capable of landing at total aircraft load at a single point, thereby, completely eliminating dispersion between individual loads. As was noted, developmental testing of the RES concept by the US Air Force is currently in progress. A joint Army/Air Force program should be carried out to determine the feasibility and acceptability of the RES concept as an operational system.

Several of the Improved Standard Airdrop Systems (ISADS) which reduce drop zone length through the consolidation of the total airdrop load of an aircraft onto significantly fewer platforms rank highly as airdrop systems. A study should be conducted to determine techniques which allow load consolidation without significant loss of operational flexibility. Simple methods of linking separately loaded low strength platforms should also be considered (the RES concept results if all loads are linked together and DCW type platforms are used).

The Multi-Extraction Parachute System (MEPS) places highly as an overall airdrop system as an alternative to concepts requiring platform redesign or load consolidation techniques. This system has been preliminarily tested with favorable results regarding small cargo trains involving two or three sequential loads.

The Extraction Parachute on Recovery Parachute (EXPOR) technique does not rate highly as a system itself. It, however, can be used advantageously on several of the ISADS systems. It should be noted that the MEPS, RES, and EXPOR concepts are really limiting cases of individual ISADS methods. MEPS essentially eliminates extraction parachute inflation time for each sequentially launched load. RES effectively is a consolidation of all loads on a single platform while the EXPOR technique is a method of minimizing extraction line length.

Variable Reefing Trajectory Control (VRTC) rates equal with the Standard Airdrop System (SADS). This technique could be used to advantage with the MEPS concept or some ISADS concepts to further shorten the drop zone requirements with little added complexity.

The study has shown Extraction Engine Systems (EES) to be poor overall airdrop systems

From the comparisons set forth in Table 6-1 it is clear that subjective judgements can influence the rating of a particular concept. Where judgements of this type are involved a conscious effort was made to be consistent throughout. In this analysis it appears that rather than specific identification of a superior technique, two or three candidates emerge as possible alternatives.

7.2 ACE Systems for Personnel Airdrop

The constraints imposed upon the study are reflected in the evaluation characteristics and the relative weights of these factors. Consequently, radical departures from conventional airdrop techniques such as bulk delivery with the EPM concept are severely hampered.

The analysis of Section 3.2 and Appendix C clearly shows that sequential exits are physically limited to time intervals on the order of 0.4 seconds. Consequently mechanical egress assist systems operating either exclusively from the ramp or the two jump doors cannot compete on a dispersion reduction basis with conventional egress methods using all available aircraft exits. Additionally, the hardware associated with mechanical devices complicate their employment and hence such systems, in the total evaluation, are less attractive than the current standard.

To utilize both the ramp and two side doors of the aircraft any adverse internal flow problems in the cargo bay must be solved. A simple method of employing flow deflecting curtains seems to be an acceptable fix.

The solution to both the static line deployment bag problem associated with ramp jumping and the traffic problem arising with four sticks simultaneously exiting the ramp and side doors is the two stage parachute system. With this deployment technique, the deployment bags are eliminated and main canopy deployment altitudes can be staggered between door and ramp jumpers to provide necessary separation. Additionally, the two stage parachute system has safety aspects equal to or better than the current T-10 system.

Systems which require modification of the standard T-10 deployment system such as RADE II and RADE III concepts (to provide for ramp and door jumping) cause severe reductions of the reliability of the descent parachute system.

The study has shown the RADE I System to clearly be the best personnel airdrop system. The simplicity of personnel walking at normal speeds to more egress points is of clear advantage over mechanical conveying systems. The simplicity of parachutists separation outside of the aircraft through the employment of variable time delayed opening Two Stage Parachutes is also attractive.

It is recommended that an Exploratory Development program be initiated to design and test a Two Stage Personnel Parachute. Additionally, it is recommended that the feasiblity of simultaneous ramp and door jumping be explored with dummy airdrops using two stage parachutes.

REFERENCES

1. Trajectory/Forces (Personnel and Door Bundle Airdrops), A Computer Program for Parachute-Payload Simulation, Gregory DeSantis, Airdrop Engineering Laboratory, U. S. Army Natick Laboratories, 1972.

2. Engineering Design Handbook, Design for Air Transport and Airdrop of Materiel, Headquarters, U. S. Army Materiel Command, AMCP 706-130, December 1967, page 3-69.

3. Technical Manual T. O. 1C-130A-9, Loading Instructions USAF Series C-130A, B, D, E Aircraft, June 1966, Page 7C-4.

4. Loading Instructions, USAF Series C-141A Type Aircraft, Technical Manual T. O. 1C-141A-9.

5. Airdrop from Outsized Cargo Aircraft, Gene A. Petry, Project Engineer, Directorate of Crew and AGE Subsystems Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

6. Notes of Meeting 30 October 1972, G. L. Fritzler (MBAssociates) with J. Leger and G. Petry, Equipment Development Branch, Delivery and Retrieval Division, Directorate for Crew and AGE, ENCDE, ASD, Wright-Patterson Air Force Base, Ohio.

7. One Hundred Ton Air Drop From C-5A Aircraft, Gene A Petry and Robert L. Hester, Jr., AIAA Aerodynamic Deceleration Systems Conference, Dayton, Ohio, September 14-16, 1970.

8. Development, Test and Evaluation of an Extraction Parachute Subsystem for Airdrop from the C-5A Aircraft, Air Force Flight Test Center, Edwards Air Force Base, California, 1969.

9. Service Test of C-5A Aircraft (Airdrop-Materiel), Third Partial Report, U. S. Army Airborne Communications and Electronics Board, Fort Bragg, North Carolina, 1971, Page 2-49.

10. RANGE (A Two Degree of Freedom, Point Mass Trajectory Computer Program), MBAssociates Staff, San Ramon, California, 1965.

11. Low Altitude Airdrop System Investigation Employing Inflation-Aided Recovery Parachutes for Extraction, Bruce W. Jezek, et al, AAI Corporation, Cockeysville, Maryland, October 1971.

12. Technical Training of Parachutists, Department of the Army Technical Manual TM 57-220, June 1968.

13. Design Analysis Report Low Altitude Troop-Type Parachute System, Northrop Ventura Report PTM-542, December 1962.

14. Airdrop Controlled Exit (ACE) Systems, Volume I, Technical Proposal, MB-P-72/16, MBAssociates, April 1972, Page 3-9.

15. Low Level Personnel Delivery Capsule, Technical Report SEG-TR-66-10, Lockheed Aircraft Corporation, October 1966.

16. Quick Change Cabin Modules Developed, E. J. Bulban, Aviation Week and Space Technology, December 11, 1972.

17. Loading Instructions - USAF Series C-141A Aircraft, Technical Manual, T.O. IC-141A-9, Change 5, Page 7B-7.

18. Airdrop of Supplies and Equipment, Department of the Army Technical Manual TM 10-500-16, Department of the Air Force Technical Order T.O. 13C7-1-13, May 1968.

19. Fluid Dynamic Drag, S. F. Hoerner, Published by Author, Bricktown, New Jersey, 1965.

APPENDIX A

SELECTED BIBLIOGRAPHY

Aircraft - Suitability for Parachute Delivery of Supplies and Equipment, Materiel Test Procedure 7-3-026, U. S. Army Test and Evaluation Command Commodity Service Test Procedure, 8 July 1970, AD874806.

Airdrop Cargo Platform Extraction-Force Transfer Coupling, Technical Information Report 18.4.4.4, University of Pittsburgh Research Staff, Washington, D.C. under Contract DA-491186-AMC-214(D) for Army Materiel Command, June 1968, AD838233.

Airdrop of Supplies and Equipment, Department of the Army Technical Manual TM-10-500-16, Department of the Air Force Technical Order T.O. 13C7-1-13, May 1968.

Airdrop Systems, Suitability of, In Aircraft, Materiel Test Procedure 7-3-030, U. S. Army Test and Evaluation Command Commodity Service Test Procedure, 22 July 1970, AD874841.

Air Movement of Troops and Equipment (Nontactical), Headquarters Department of the Army Technical Manual TM55-450-15, June 1971.

Altgelt, R. E., Low Altitude Airdrop System for Personnel (Exploratory) Development), Goodyear Aerospace Corp. for U. S. Army Natick Labs., Technical Report 69-68-AD, November 1968, AD852090L.

Bender, Jr., Major William, "Airdrop", Air Force Review, Air University Review, May-June 1967, AD825788.

Bibliography of Technical Publications and Papers, July 1968 - June 1969, Technical Report 70-1, July 1969, U. S. Army Natick Laboratories, AD696791.

Bibliography of Technical Publications and Papers, July 1969 - June 1970, Technical Report 71-1-TL, July 1970, U. S. Army Natick Laboratories, AD712993.

Bibliography of Technical Publications and Papers, July 1971 - June 1972, Technical Report 73-1-TL, U. S. Army Natick Laboratories, AD749249.

Black, Capt. James M., Development, Test and Evaluation of an Extraction Parachute Subsystem for Airdrop from the C-5A Aircraft, U. S. Air Force Flight Test Center, Edwards Air Force Base Technical Report No. 69-29, October 1969, AD860802.

Black, W. L., and Farinacci, A. L., Systems for Rapid Preparation of Airdrop Loads, AAI Corp. for U. S. Army Natick Labs., Technical Report 72-79-AD, July 1972, AD750705.

Bulban, Erwin J., "Quick-Change Cabin Modules Developed", Aviation Week and Space Technology, 11 December 1972, p. 37-41.

C-130A Aircraft Flight Manual, USAF Series, AF33(600)-22286, 11 June 1966, T.O. 1C-130A-1.

Chakoian, George, A Parachute Retrorocket Recovery System for Airdrop of Heavy Loads, Airdrop Engineering Laboratory, U. S. Army Natick Labs., Technical Report 70-34-AD, AD699342.

Chang, Wen Shing and Ripperger, E. A., Stress and Deflections in Type II and Type IV Airdrop Platforms, U. S. Army Natick Laboratories Technical Report 70-56-AD, December 1969, AD711556.

Ducote, Richard J., Evaluation of the A/A32H-4 Dual Rail Cargo Handling System for Airdrop and Low Level Cargo Deliveries, Air Force Flight Test Center, Edwards Air Force Base Technical Report No. 67-35, March 1968, AD830011.

Esland, Major W. R., Further Air-Drop Trials of Stressed Supply Platforms, by Extractor Retarder Method, Ministry of Technology, Aeroplane and Armament Experimental Establishment, Boscombe Down, London, A&AEE Note No. 3050, 11 February 1969, AD880469.

Esland, Major W. R., Air-Drop of Heavy Stressed Platforms by Reefed Main Extraction, Ministry of Technology, Aeroplane and Armament Experimental Establishment, Boscombe Down, A&AEE Note No. 3007, 26 October 1967, AD825349.

Fedotov, Eng. Col. N., U.S.S.R., Motor Vehicles on Parachutes, U. S. Army Foreign Science and Technology Center, FSTC-HT-23-574-71, AD734228.

Frisbee, J. L., "The Air War in Vietnam", Air Force Magazine, November 1972, p. 40-42.

Gionfriddo, Maurice P., Two-Body Trajectory Analysis of a Parachute-Cargo Airdrop System, U. S. Army Natick Laboratories Technical Report 69-80-AD, April 1969, AD690808.

Goodrick, T. F., Wind Tunnel Studies of the Pressure Distribution and the Flow Field in the Wake of the Lockheed C-141A Starlifter Jet Transport Aircraft, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base Technical Report AFFDL-TR-67-1 3, May 1968, AD835380.

Haak, E. L., and Thompson, R. E., Analytical and Empirical Investigation of the Drag Aera of Deployment Bags, Cargo Platforms and Containers, and Parachutists, University of Minnesota, prepared for Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Technical Report AFFDL-TR-671166, July 1968, AD840082.

Hall, Dexter, Service Test of C-5A Aircraft (Airdrop - Materiel), Third Partial Report, U. S. Army Airborne, Communications and Electronics Board, Fort Brass, North Carolina, December 1971, AD890766L.

Hanley, Donald L., and Bement, Russell P., C-141A Category II Aerial Delivery System Evaluation, Technical Report No. 66-45, June 1967, AD817231.

Hoerner, A. J., Air-Drop of Sealdrum Bulk Fuel Container Using Canopy-First Deployed Parachutes, AFRAEA, Aeroplane and Armament Experimental Establishment, Boscombe Down, London, A&AEE Note No. 3079, 11 November 1970, AD887283.

Hunter, Hnery J., Evaluation Tests of an Emergency Release Assembly for Use in Parachute Extraction Systems, Air Force Flight Tsst Center, Edwards Air Force Base, Technical Report No. 67-22, November 1967, AD824204.

Hunter, H. J. and Black, J. M., Heavy Duty 28-Ft. Ringslot Extraction Parachute Tests, Air Force Flight Test Center, Edwards Air Force Base, Technical Report No. 68-5, February 1968, AD828719.

Hunter, Henry J., Performance Evaluation of a 25,000 to 35,000 Pound Capacity Extraction System for the C-141A Aircraft, FTC-TR-67-23, AD824145.

Jezek, Bruce W., and Mueller, Kenneth E., Low Altituae Airdrop System Investigation Employing Inflation-Aided Recovery Parachutes for Extraction, AAI Corporation for Airdrop Engineering Laboratory, U. S. Army Natick Laboatories, Technical Report 72-15-AD, October 1971, AD735375.

Laine, Charles O., Development and Evaluation of a C-130 Aircraft Low Altitude Parachute Extraction System (LAPES) for Aerial Delivery of Single and Tandem Cargo Platforms at Ground Proximity, FTC-TR-68-3, AD828563.

Lambe, G., Air-Drop of Medium Stressed Platforms Using the Mains Extraction Technique, Ministry of Technology, Aeroplane and Armament Experimental Establishment, Boscombe Down, London, 6th Part of Report No. AEE/950, 14 November 1969, AD892393.

Lau, Richard A., Preliminary Investigation of Concepts for Low-Altitude Airdrop of Personnel-Exploratory Development, Goodyear Aerospace Corporation for U. S. Army Natick Laboratories under Contract No. DA10-129-AMC-855(N), Final Report GER-12888, 30 December 1966, AD667401.

Loading Instructions Technical Manual T.O. 1C-141A-9, USAF Series C-141A Aircraft, AF 33(657)-8835.

Low Level Personnel Delivery Capsule, Lockheed Georgia Company Technical Report SEG-TR-66-10 for Systems Engineering Group, Wright-Patterson Air Force Base, October 1966.

Maak, Eugene, Calculated Values of Transient and Steady State Performance Characteristics of Man-Carrying, Cargo, and Extraction Parachutes, Minnesota University, Minneapolis Department of Aeronautics.

Mansfield, D. L., Preliminary Investigation of Ballute-Flexible Rotor Concept for Low-Altitude Cargo Airdrop, U. S. Army Natick Labs. Final Report GER-12970, August 1966, AD670984.

Manson, A. R., et al., Minimum Drop Altitudes and Horizontal Distances for High Altitude, Reefed Parachute Drops, USAF Tactical Airlift Center, Pope Air Force Base, N.C., July 1969, AD693152.

Martin, K. L., Ramirez, R. E., Franzen, R. V., Evaluation of the C-130E Stability and Control Characteristics and the A/A32H-4 Dual Rail Cargo Handling System During Low Level Cargo Deliveries, Technical Report No. 66-43, March 1967, AD810923.

Michal, Joseph L., et al., Parachute Retrorocket Airdrop System, U. S. Army Natick Laboratories Technical Report 72-16, December 1970, AD736361.

Miller, C. W., Alford, D. E., Komodowsky, H. E., and Stockes, T. H., Preliminary Investigation of Trolley Low Altitude Airdrop Concept, U. S. Army Natick Laboratories Technical Report 68-55-AD, April 1968, AD671682.

Oates, Ronald W., Low Altitude Airdrop of Personnel (LAAP), Stencel Aero Engineering Corporation for U. S. Army Natick Labs., Contract No. DAAG17-67-C-0205, October 1968, AD851410L.

Parachute Technology, Volume I of II Volumes, a DDC Bibliography, DDC-TAS-79-87-1, May 1971, AD724500.

Pendulum Release Extraction Parachute System Preps, TAC Test 68-224 Test Order, Tactical Air Command, Pope Air Force Base, N.C., November 1968, AD844102.

Petry, Gene A., and Hester, Robert L., One-Hundred Ton Airdrop from a C-5A Aircraft, AIAA Paper No. 70-1203, presented at the AIAA Aerodynamic Deceleration Systems Conference, Dayton, Ohio, September 14-16, 1970.

Petry, Gene A., Airdrop from Outsized Cargo Aircraft, Directorate of Crew and AGE Subsystems Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Podevin, Wg. Cdr. G. A., O.B.E., R.A.F., Testing and Assessment of Two Types of Trefoil Parachute Assemblies for the Low Level Delivery of Paratroops, Royal Aircraft Establishment Technical Report 69-69, August 1969, AD863307.

Proceedings of Retardation and Recovery Symposium, Technical Documentary Report No. ASD-TDR-63-329, Flight Accessories Laboratory, Wright-Patterson Air Force Base, Ohio, May 1963.

Scher, Stanley H., and Young, Irene G., Drag Coefficients for Partially Inflated Flat Circular Parachutes, Langley Research Center, NASA Technical Note NASA TN D-6423, September 1971.

Slayman, Robert G., Bair, Herbert Q., Rathbun, Thomas W., 500-Pound Controlled Airdrop Cargo System, Goodyear Aerospace Corporation Final Report on Contract DAAJ02-68-C-0040, USAAVLABS Technical Report 70-31, September 1970, AD877587.

Technical Training of Parachutists, Department of the Army Technical Manual TM 57-220, June 1968.

Tingdahl, M. A., G-12D Low Altitude Aerial Delivery System (LAADS), Air Force Flight Test Center, Edwards Air Force Base Technical Report No. 67-8, June 1967, AD816783.

Varley, Major J. R., and Brown, S. J. W., Argosy C. MK. 1 Gravity Extraction of 1 Ton Container Sticks, Ministry of Technology, Aeroplane and Armament Experimental Establishment, Boscombe Down, 17th Part of Report No. AAEE/936, 19 April 1967, AD824566.

Varley, Major J. R., Heavy Air-Drop Techniques, Ministry of Technology, Aeroplane and Armament Experimental Establishment, Boscombe Down, London, 1st Part of Report No. AAEE/950, 27 April 1967, AD822917.

Webb, R. D., Low Altitude Troop-Type Parachute System, Design Analysis Report, Northrop Ventura Report No. PTM-542, 7 December 1962.

White, E. L., Bronn, C. E., Sturgeon, R. F., et al., Study of Heavy Equipment Aerial Delivery and Retrieval Techniques, The Lockheed-Georgia Company, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base Technical Report No. AFFDL-TR-66-97, January 1967, AD810301.

Worley, Major John N., A Comparative Study of the Ground Proximity Extraction System and the Low Altitude Parachute Extraction System as Methods of Tactical Aerial Delivery to Combat Forces, A Study Thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, August 1969, SLSR-40-69, AD863999.

APPENDIX B

ACE PROGRAM PLAN AND SCHEDULE

1.0 HISTORICAL AND OPERATIONAL REVIEW

- 1.1 Literature Search
- 1.1.1 Define Existing Concepts
- 1.1.2 Acquire Test and Performance Data Concerning Existing Concepts
- 1.1.3 Acquire Development and Operational Cost Data for Existing Concepts
- 1.2 Operational Review
- 1.2.1 Observe Current Personnel and Platform Load Drop Techniques
- 1.2.2 Interview Operational Personnel for Suggested Improvements
- 1.2.3 Obtain Candidate Aircraft Performance Parameters and Structural Limitations from Airframe Manufacturers
- 1.2.4 Obtain Candidate Aircraft Loading and Operational Information from USAF
- 1.2.5 Interview Government Agencies and Contractors as to Current Developments in Airdrop Techniques

2.0 CONCEPT FORMULATION

- 2.1 Preliminary Analysis
- 2.1.1 Parametric Study of Trajectories of Airdropped Cargo and Personnel
- 2.1.2 Determination of Minimum Spacing Allowable for Parachutists
- 2.1.3 Generalized Calculations of Force and Power Requirements for Cargo Extraction and Personnel Conveying Systems

2.1.4 Determination of Airdrop System Physical Constraints Imposed by Airframe Limitations, Aircraft Performance, and Aircrew Proficiency

2.2 Invent New Paratroop Drop Concepts

2.3 Invent New Concepts for Rapid Sequential Extraction of Platform Loads and Consider Trajectory Modification Techniques

3.0 SYSTEM SYNTHESIS

3.1 Definition of New Systems for Personnel Airdrop

3.1.1 System Operation

3.1.2 System Configuration

3.1.3 System Dynamics

3.1.4 System Performance Parameters

3.1.4.1 Drop Zone Dispersion

3.1.4.2 Weight

3.1.4.3 Safety and Reliability

3.1.4.4 Aircraft Modification

3.1.4.5 Maintenance Requirements

3.1.4.6 Logistical Requirements

3.1.4.7 Initial Cost

3.1.4.8 Operating Cost

3.2 Definition of New Systems for Cargo Airdrop

3.2.1 System Operation

3.2.2 System Configuration

3.2.3 System Dynamics

3.2.4 System Performance Parameters

3.2.4.1 Drop Zone Dispersion

3.2.4.2 Weight

3.2.4.3 Safety and Reliability

3.2.4.4 Required Aircraft Modification

3.2.4.5 Maintenance Requirements

3.2.4.6 Logistical Requirements

3.2.4.7 Initial Cost

3.2.4.8 Operating Cost

3.3 Selection of Promising New Concepts for System Evaluation

3.3.1 Development Time Less than 4 - 6 Years

3.3.2 Systems Must Not Require Major Aircraft Modification

3.3.3 Systems Must Not Compromise Aircraft or Personnel Safety

3.3.4 System Operation Must Not Depend on Exceptional Aircrew Proficiency

4.0 SYSTEM EVALUATION

4.1 Paratroop Drop Systems

4.1.1 Determine a Figure of Merit Scheme to be Applied to all Existing Concepts and the Selected New Concepts Considering:

4.1.1.1 Dispersion Improvement over T-10 Static Line Deployed Parachute/1.0 Second Interval

4.1.1.2 Weight

4.1.1.3 Development Cost

4.1.1.4 Operational Cost

4.1.1.5 Flexibility and Logistical Requirements

4.1.1.6 Interchangeability with Platform Load Drop Concepts

4.2 Cargo Drop Systems

4.2.1 Define a Standard of Comparison for Drop Zone Dispersion of Platform Loads

4.2.2 Determine a Figure of Merit Scheme to be Applied in Evaluating Existing and Selected New Concepts Considering:

4.2.2.1 Dispersion Improvement over Selected "Standard" System

4.2.2.2 Weight

4.2.2.3 Development Cost

4.2.2.4 Operational Cost

4.2.2.5 Flexibility and Logistical Requirements

4.2.2.6 Interchangeability with Paratroop Drop Concepts

5.0 REPORTS

5.1 Monthly Status Reports

5.2 Final Report

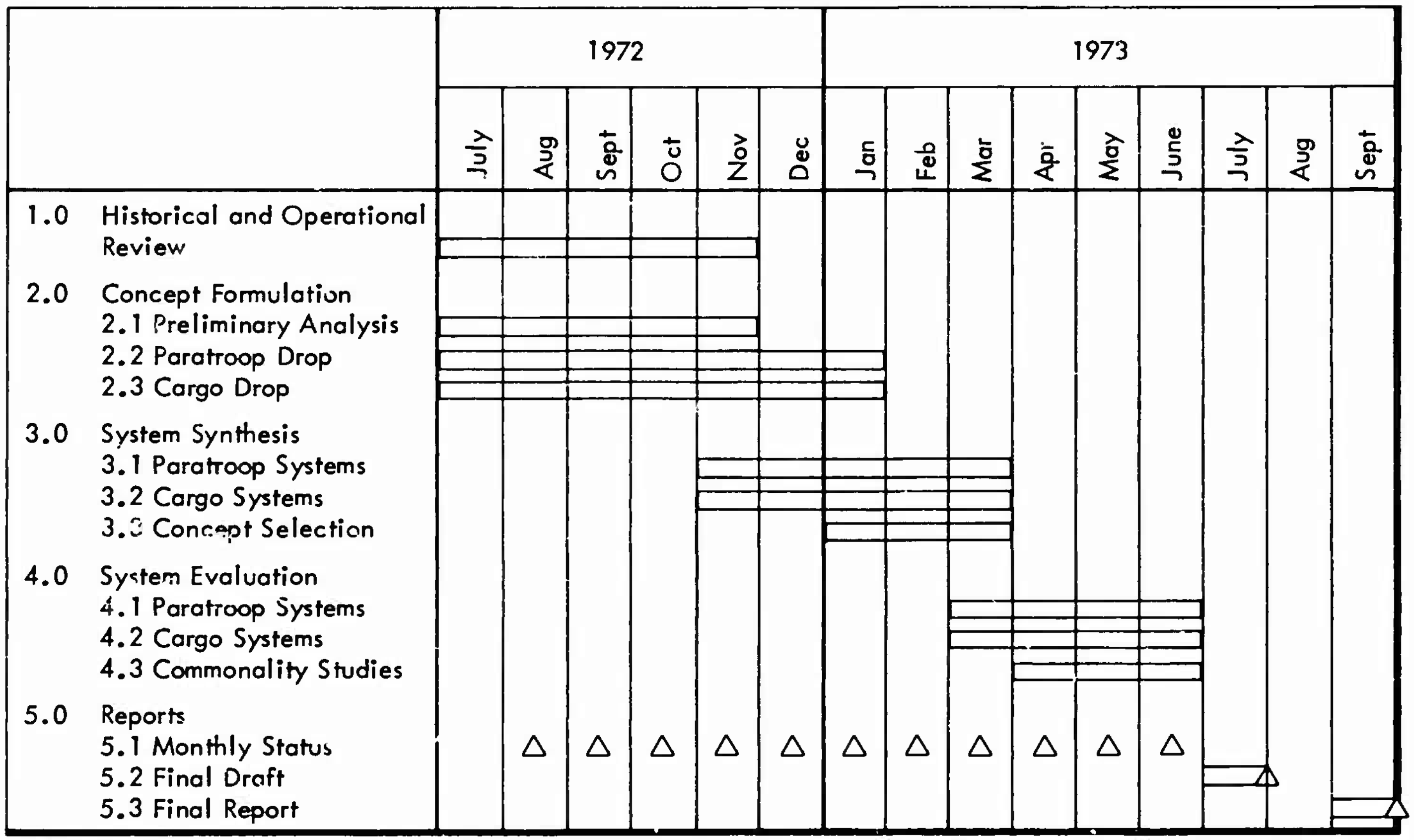


FIGURE B-1
ACE OVERALL PROGRAM SCHEDULE

APPENDIX C

SIMPLIFIED METHOD OF CALCULATING PARACHUTIST SEPARATION DISTANCES AND DROP ZONE LENGTH

For paratroopers jumping with the T-10 parachute, the drop zone length is approximately (neglecting wind) the distance between the point at which the first man egressed from the airplane and the last man egressed.

As a guide to the required egress rate per stick, a map of drop zone length vs. egress rate for the airplane velocity limits is needed. To simplify the calculations, the average ground separation distance between two jumpers per stick vs. the average exit interval per jumper per stick will be calculated and the results converted to drop zone length vs. exit time interval. These results are presented in Figures B-1 and B-2.

Assuming a controlled egress system is capable of very short egress intervals, there must be a practical limit beyond which egress interval may not be reduced. This limit is imposed as minimum separation distance between jumpers is reduced to the point where safety is compromised due to physical or aerodynamic interference. A simplified calculational scheme is presented to identify minimum separation distances between jumpers as a function of egress interval. The calculations presented roughly show how far a parachutist moves aft of his egress point due to aerodynamic drag (before parachute opening) during the time interval between jumpers. As parachutes open the separation rapidly increases.

For a constant C_D and density and gravity free event

$$a = -\frac{\frac{1}{2}\rho V^2 C_D A}{m}$$

$$\lambda = \frac{m}{\frac{1}{2}\rho C_D A}$$

$$a = -\frac{V^2}{\lambda} = \frac{dv}{dt}$$

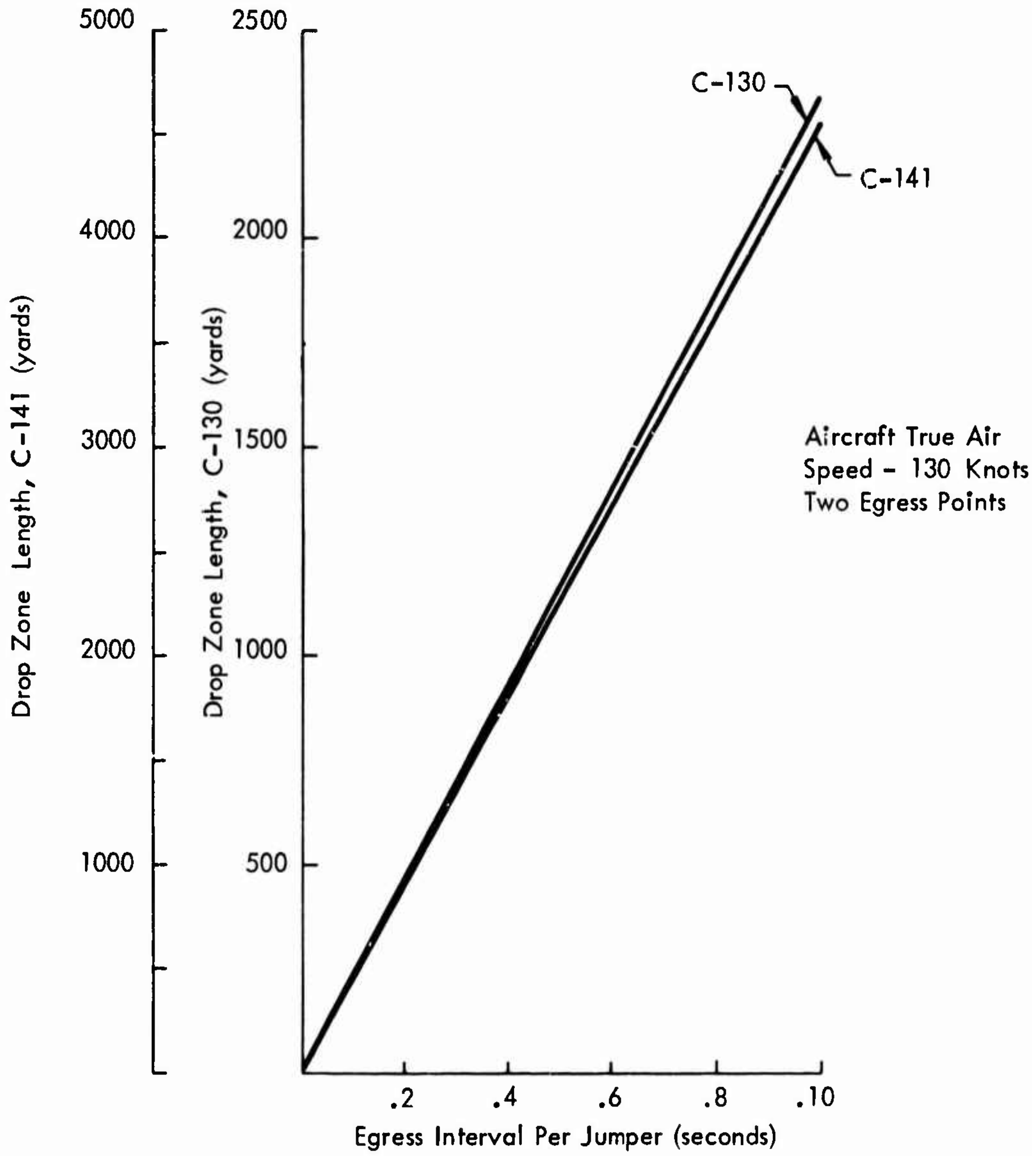


FIGURE C-1
DROP ZONE LENGTHS AS FUNCTIONS OF
JUMP INTERVAL AT AN EGRESS POINT

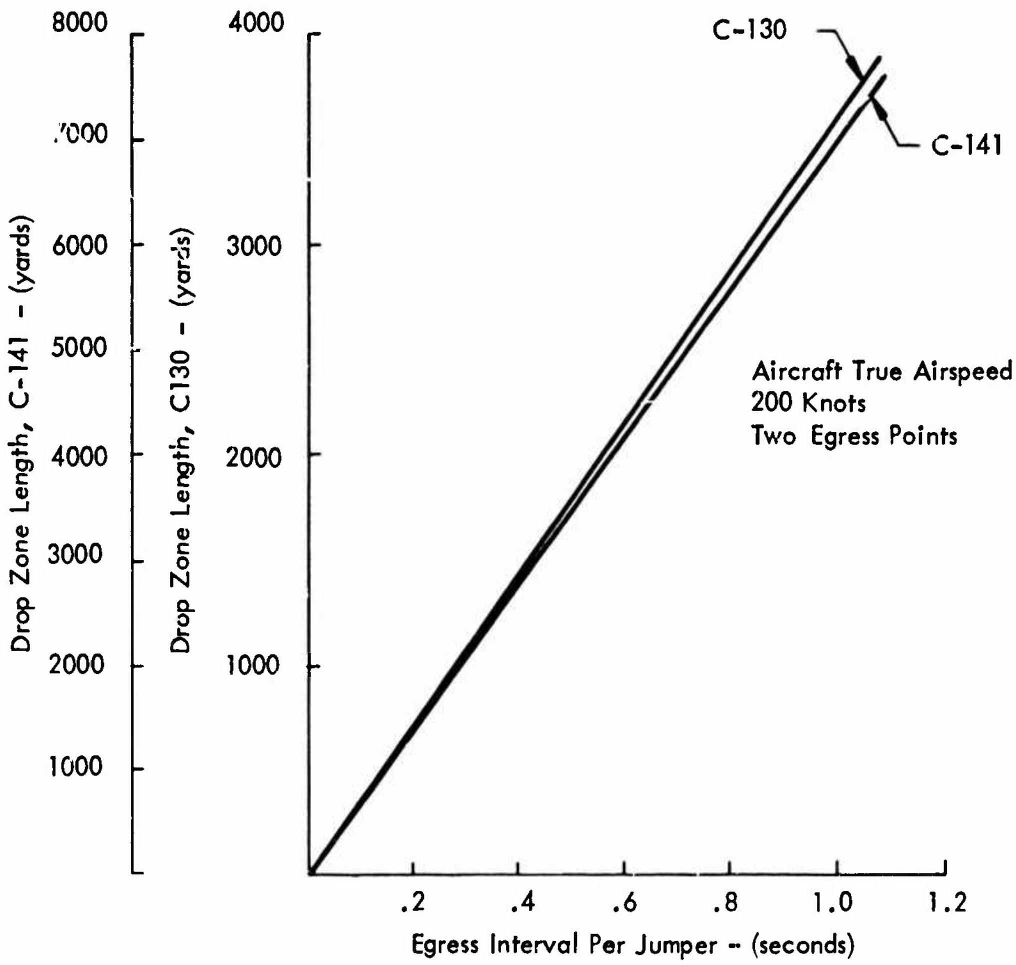


FIGURE C-2
DROP ZONE LENGTHS AS FUNCTIONS OF JUMP INTERVAL AT AN EGRESS POINT

From $$\int_o^t \frac{dv}{v^2} = - \int_o^t \frac{dt}{\lambda}$$

$$\frac{1}{\upsilon} = \frac{1}{\upsilon_o} + \frac{t}{\lambda}$$

or

$$\upsilon = \frac{1}{\frac{1}{\upsilon_o} + \frac{t}{\lambda}} = \frac{ds}{dt}$$

$$\int_o^t ds = \int_o^t \frac{1}{\frac{1}{\upsilon_o} + \frac{t}{\lambda}} dt$$

$$\therefore S = \lambda \ \ell n \frac{\upsilon_o}{\lambda} t + 1$$

To check for gravitational effects

At 1 sec, $\upsilon = gt = 32.2$ ft/sec

$S = \frac{1}{2} gt^2 = 16.1$ ft

Thus gravity may be neglected for t less than one second.

$$S = \lambda \ \ell n \frac{\upsilon_o}{\lambda} t + 1$$

$$\lambda = \frac{m}{\frac{1}{2} \rho C_D A}$$

where

C_DA = 9 ft^2 (Reference 18)

$m = \frac{250}{g}$ = 7.775 slugs (combat loaded paratrooper)

ρ500ft = .002344 slugs/ft^3

ρ12,000 ft = .001649 slugs/ft^3 (terrain 10,000 ft. above sea level, airplane 2,000 ft. above terrain)

$$\therefore \lambda_{min} = \lambda_{500} = 737 \text{ ft}$$

$$\lambda_{max} = \lambda_{12,000} = 1,047 \text{ ft}$$

$$\upsilon_{o_{min}} = 130 \text{ knots} = 218.5 \text{ ft/sec}$$

$$\upsilon_{o_{max}} = 200 \text{ knots} = 337.6 \text{ ft/sec}$$

Presently the nominal egress rate for paratroopers combat loaded is one jumper per second per stick. Thus, this is the minimum egress rate used in the calculations.

The separation distances calculated are minimum distances as the parachutes are assumed to be uninflated in this one second interval. Once the parachute deploys, the value of C_DA increases by a factor of 40 and the jumper would slow down much more rapidly. However the inflation time of a T-10 parachute is greater than one second.

Calculated results using the analysis described are included in Tables C-1 and C-2 and in Figures C-1 through C-4.

Table C-1

Drop Zone Lengths for Aircraft True Airspeed 130 Knots @ 500 Feet Altitude

Egress Time Interval Δt per Jumper (sec)	Minimum Separation Distance = $\Delta S = V_o t - S$	Egress Rate	Drop Zone Length = $V_o \Delta t$ x Jumpers	
	per Jumper (ft)	One Stick (Jumper/sec)	C-130 1 Stick Total 32 Jumpers (yards)	C-141 1 Stick Total 62 Jumpers (yards)
.1	-	10.0	234	453
.2	1.1	5.0	468	907
.3	3.15	3.33	702	1,360
.4	4.5	2.5	936	1,814
.5	7.05	2.0	1,170	2,267
.6	9.9	1.67	1,404	2,721
.7	13.35	1.43	1,638	3,174
.8	17.5	1.25	1,872	3,628
.9	22.25	1.11	2,106	4,081
1.0	26.7	1.0	2,340	4,535

Table C-2

Drop Zone Lengths for Aircraft True Airspeed 200 Knots @ 12,000 Feet Altitude

Egress Time Interval per Jumper per Stick Δt (sec)	Minimum Separation Distance = $\Delta S = V_o t - S$	Egress Rate	Drop Zone Length = $V_o \Delta t$ x Jumpers	
	per Jumper (ft)	One Stick (Jumpers/sec)	C-130 1 Stick Total 32 Jumpers (yards)	C-141 1 Stick Total 62 Jumpers (yards)
.1	.26	10.0	360	698
.2	1.87	5.0	720	1,395
.3	3.98	3.33	1,080	2,093
.4	7.24	2.5	1,440	2,791
.5	11.6	2.0	1,800	3,488
.6	16.26	1.67	2,160	4,186
.7	22.31	1.43	2,520	4,883
.8	28.58	1.25	2,880	5,581
.9	35.84	1.11	3,240	6,279
1.0	43.6	1.0	3,600	6,976

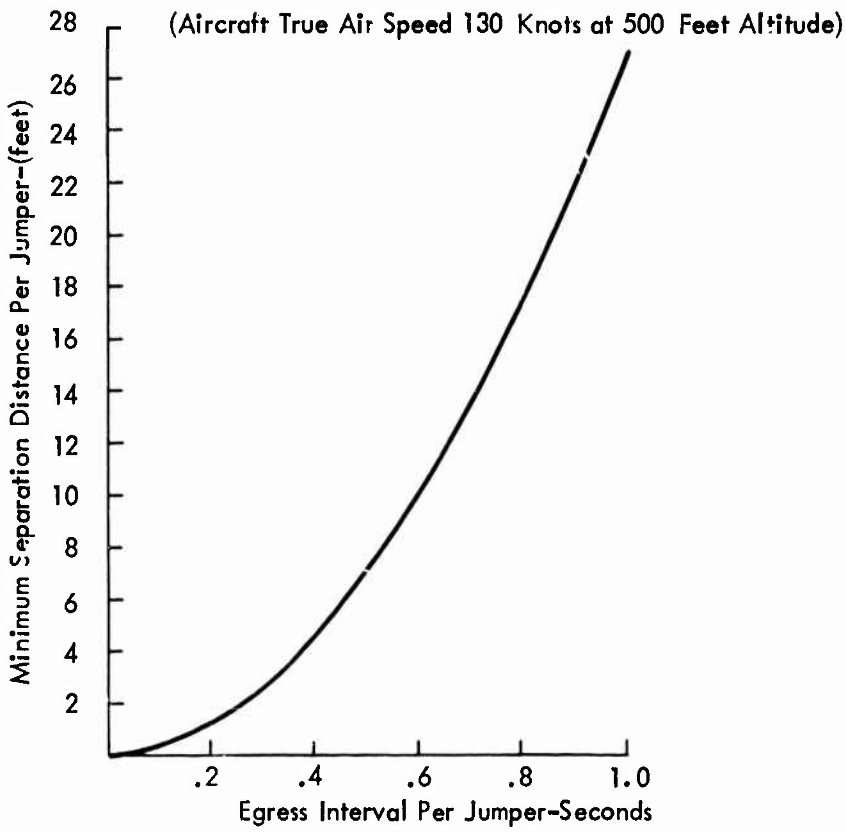


FIGURE C-3.
MINIMUM SEPARATION DISTANCE PER JUMPER

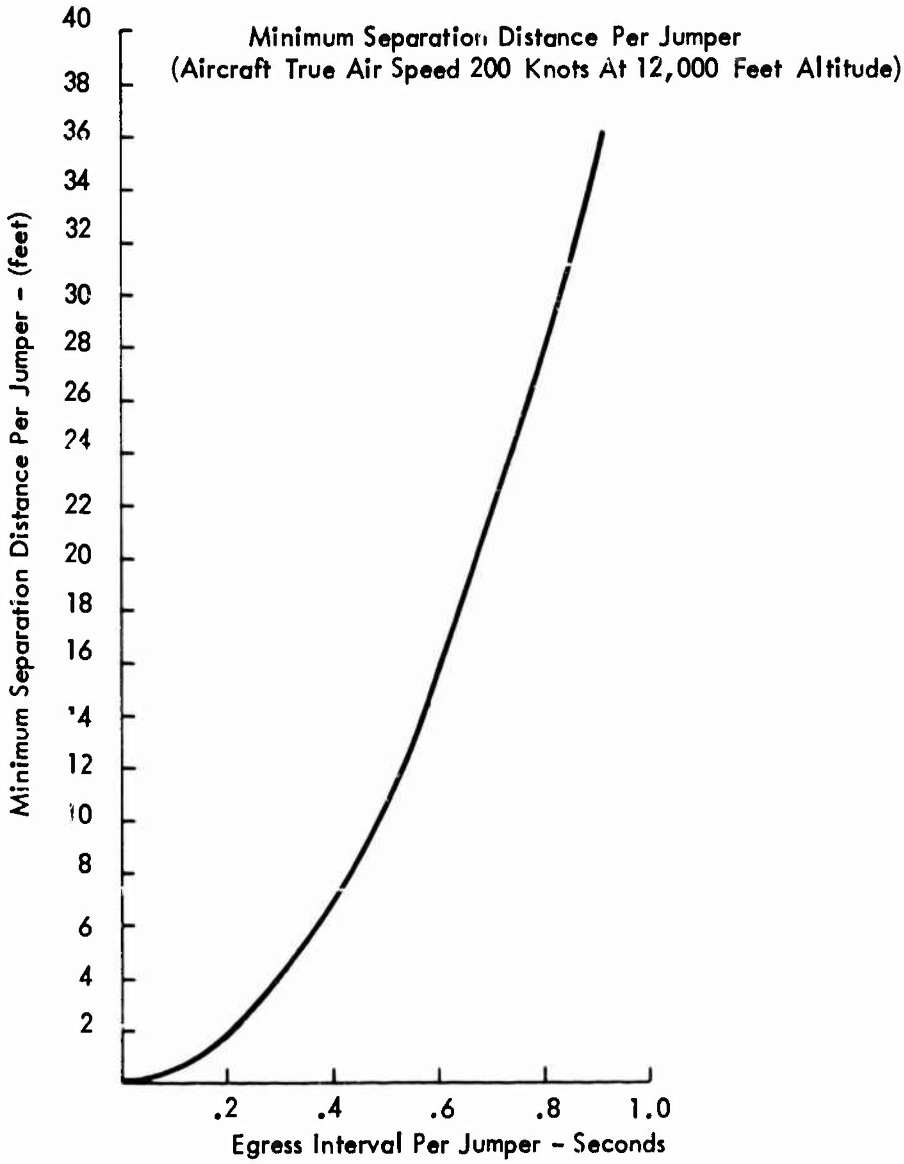


FIGURE C-4.
DROP ZONE LENGTHS AS FUNCTIONS OF
JUMP INTERVAL AT AN EGRESS POINT

APPENDIX D

ESTIMATE OF PERSONNEL CONVEYOR SYSTEM POWER REQUIREMENTS

A combat loaded paratrooper cannot be expected to move much more rapidly than he does presently without some type of mechanical assist. Conveyor systems have the advantages of increasing egress rate, maintaining an even interval between jumpers on a stick, and synchronizing two or more sticks.

As an estimate of the power required to drive a conveyor system, a frictionless and massless conveyor system is used in a model where the only mass to be moved are the paratroopers. The power requirements are calculated only for the first man to exit. Therefore the acceleration distance and exit velocity are those of the first man to exit. The total power required is 64 (C-130) or 123 (C-141) times that required for the first man.

A correction for the aircraft deck angle is also computed. The graphs show a negative power requirement at positive deck angles. This negative power is the power required to retard the conveyor system to a desired acceleration less than $g \sin \alpha$ (gravitational acceleration component on the aircraft longitudinal axis).

$$\text{Power} = P = \frac{dw}{dt} = \frac{d(Fs)}{dt} = \frac{d(mas)}{dt}$$

$$P = m\left(a\frac{ds}{dt} + s\cancelto{0}{\frac{da}{dt}}\right)$$

For a constant force (acceleration)system $\frac{da}{dt} = 0$

$$\therefore P = mav$$

$$t = \frac{2s}{v}$$

$$s = \frac{1}{2} at^2 = 2a\frac{v^2}{s^2}$$

$$a = \frac{v^2}{2s}$$

$$\therefore P = \frac{mv^3}{2s} \quad \frac{\text{ft-lb}}{\text{sec}}$$

Converting to horsepower

$$P = \frac{mv^3}{2(550)s} \quad \text{HP}$$

or

$$P = \frac{\omega v^3}{1100\,g\,s} \quad \text{HP}$$

where

P = power in horsepower

ω = mass in lbm

v = velocity in ft/sec

s = distance in ft

$g = 32.2 \frac{\text{lbm-ft}}{\text{lbf-sec}^2}$

$$\text{Deck angle acceleration} = -g \sin \alpha$$

$$\alpha = \text{deck angle}$$

$$P = (mv)\,a$$

$$\therefore P = mv\,(a_{\alpha = 0} + a_{\alpha}) = (mv)\,(a_{\alpha = 0} - g \sin \alpha)$$

$$P = (mv)\,a_{\alpha = 0} \left(1 - \frac{g \sin \alpha}{a_{\alpha = 0}}\right)$$

$$\therefore P = P_{\alpha = 0} \left(1 - \frac{g \sin \alpha}{a_{\alpha = 0}}\right)$$

Figure D-1 shows the required acceleration of a conveyor to attain a given parachutist exit velocity in several acceleration distances. Figures D-2 through D-5 show conveyor power required to accelerate an individual man, 64 men (C-130) and 123 men (C-141) to various exit velocities at various aircraft deck angles for acceleration distances of 5, 6, 8, and 10 feet respectively.

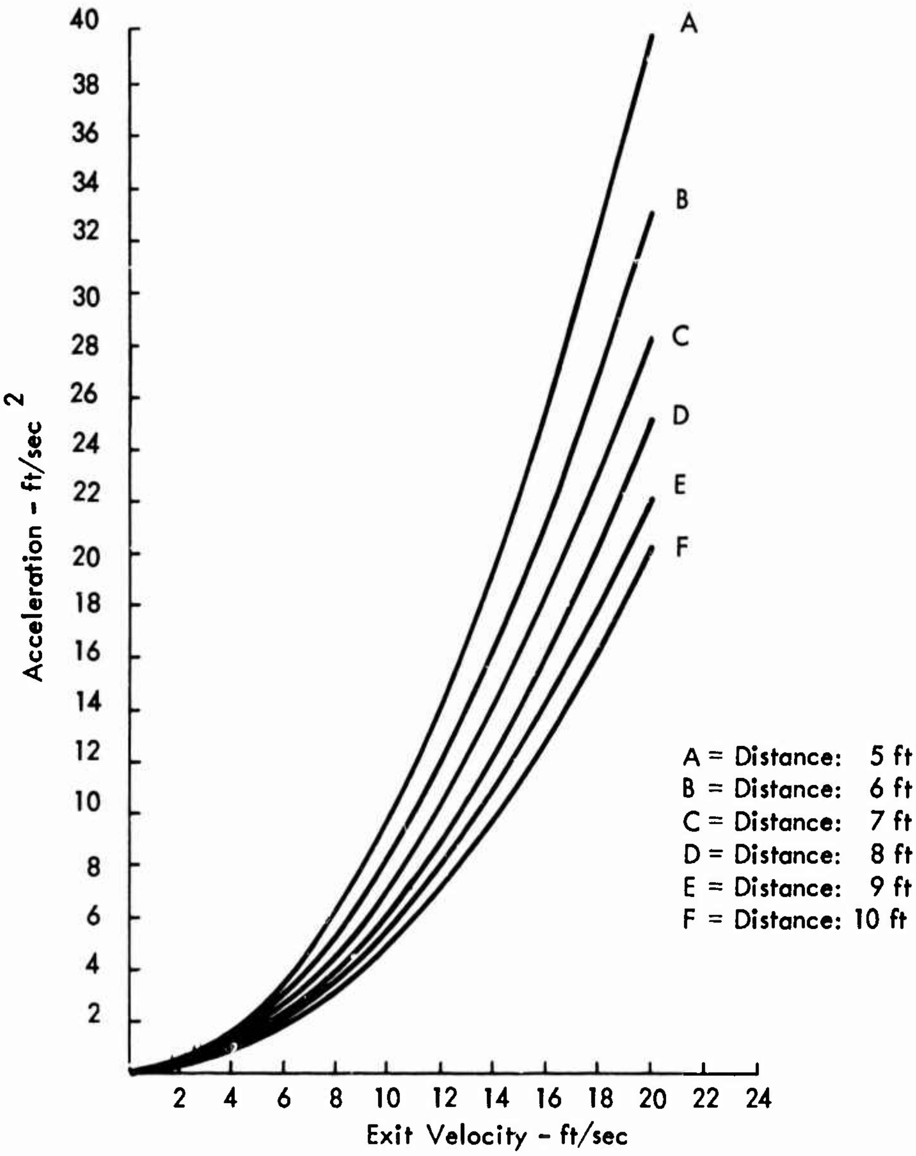


FIGURE D-1.
CONVEYOR ACCELERATION REQUIRED TO PRODUCE AN EXIT VELOCITY FOR SEVERAL ACCELERATION DISTANCES

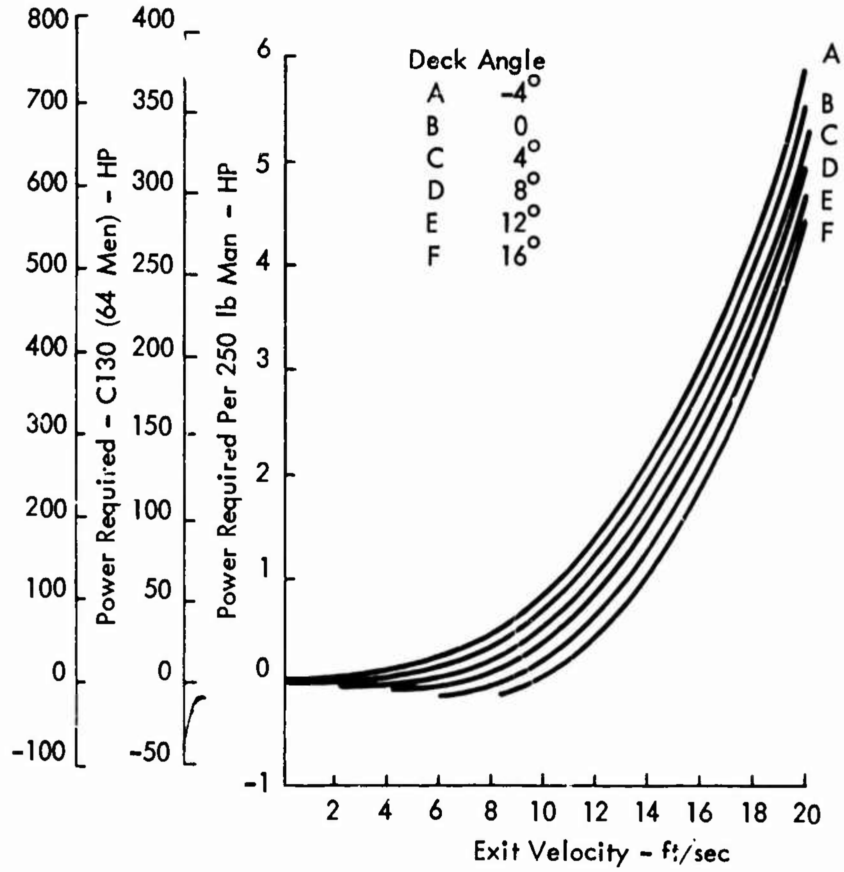


FIGURE D-2
POWER REQUIREMENTS AS A FUNCTION OF EXIT VELOCITY
ACCELERATION DISTANCE = 5 FEET

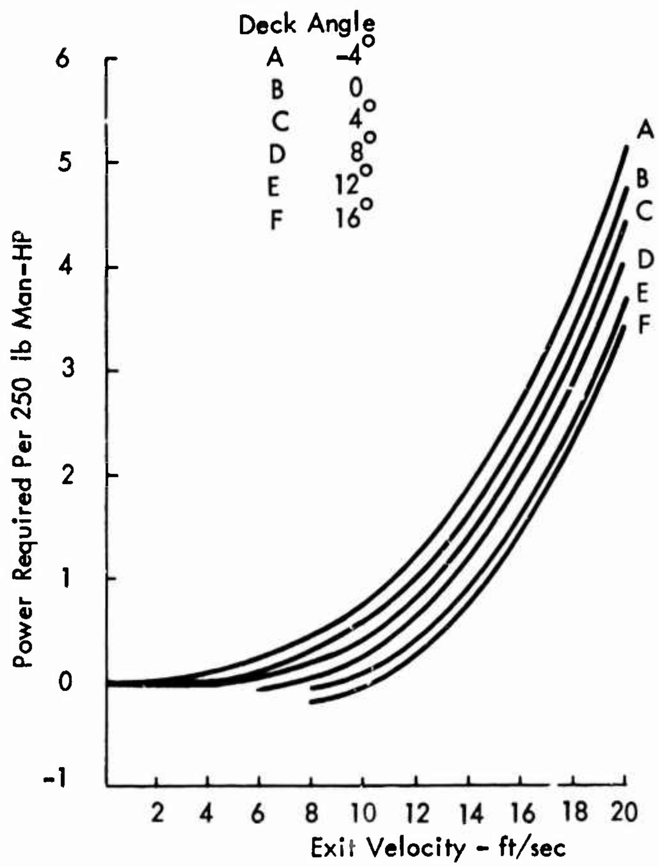


FIGURE D-3.
POWER REQUIREMENTS AS A FUNCTION OF EXIT VELOCITY
ACCELERATION DISTANCE = 6 FEET

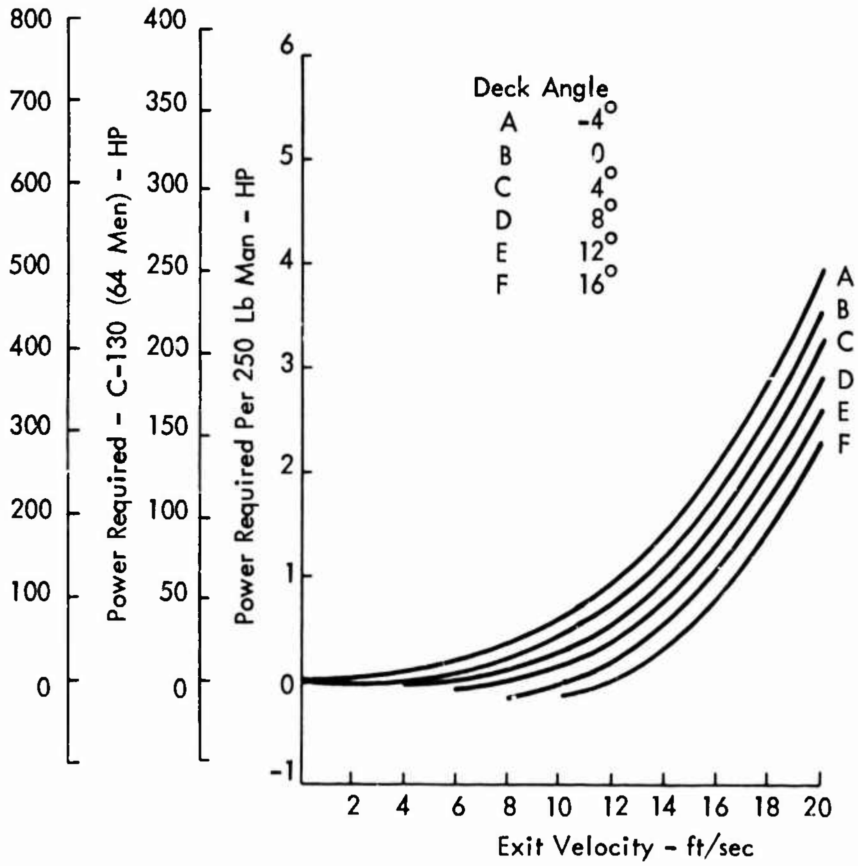


FIGURE D-4.
POWER REQUIREMENTS AS A FUNCTION OF EXIT VELOCITY
ACCELERATION DISTANCE = 8 FEET

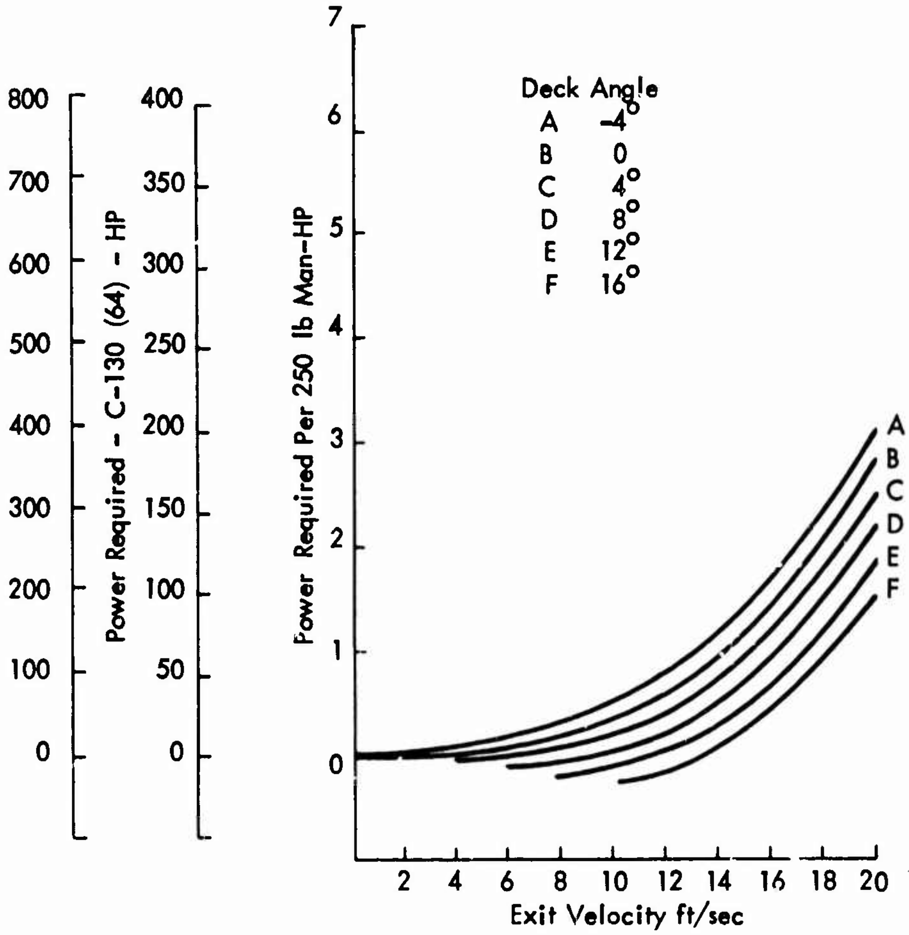


FIGURE D-5.
POWER REQUIREMENTS AS A FUNCTION OF EXIT VELOCITY
ACCELERATION DISTANCE - 10 FEET